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(54) Title: GLYPHOSATE TOLERANT 5-ENOLPYRUVYL SHIKIMATE-3-PHOSPHATE SYNTHASES

## (57) Abstract

Genes encoding class II EPSPS enzymes are disclosed. The genes are useful in producing transformed bacteria and plants which are tolerant to glyphosate herbicide. Class II EPSPS genes share very little homology with known, Class I EPSPS genes, and do not hybridize to probes from Class I EPSPS's. The Class II EPSPS enzymes are characterized by being more kinetically efficient than Class I EPSPS's in the presence of glyphosate. Plants transformed with Class II EPSPS genes are also disclosed as well as a method for selectively controlling weeds in a planted crop field.

DNA ENCODING CLASS II EPSPS 5'-ENOL PYRUVYL SHIKIMATE-3-PHOSPHATE SYNTHASE + FOR PRODUCING PLANTS TOLERANT TO GLYPHOSATE HERBICIDES

Fig 2 532

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GLYPHOSATE TOLERANT  
5-ENOLPYRUVYLSHIKIMATE-3-PHOSPHATE SYNTHASES

This is a continuation-in-part of a copending U.S. patent application having serial number 07/576,537, filed August 31, 1990 and entitled "Glyphosate Tolerant 5-Enolpyruvylshikimate-3-Phosphate Synthases."

BACKGROUND OF THE INVENTION

This invention relates in general to plant molecular biology and, more particularly, to a new class of glyphosate tolerant 5-enolpyruvylshikimate-3-phosphate synthases.

Recent advances in genetic engineering have provided the requisite tools to transform plants to contain foreign genes. It is now possible to produce plants which have unique characteristics of agronomic importance. Certainly, one such advantageous trait is more cost effective, environmentally compatible weed control via herbicide tolerance. Herbicide-tolerant plants may reduce the need for tillage to control weeds thereby effectively reducing soil erosion.

One herbicide which is the subject of much investigation in this regard is N-phosphonomethylglycine commonly referred to as glyphosate. Glyphosate inhibits the shikimic acid pathway which leads to the biosynthesis of aromatic compounds including amino acids, plant hormones and vitamins. Specifically, glyphosate curbs the conversion of phosphoenolpyruvic acid (PEP) and 3-phosphoshikimic acid to 5-enolpyruvyl-3-phosphoshikimic acid by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (hereinafter referred to as EPSP synthase or EPSPS).

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It has been shown that glyphosate tolerant plants can be produced by inserting into the genome of the plant the capacity to produce a higher level of EPSP synthase in the chloroplast of the cell (Shah et al., 1986) which enzyme is preferably glyphosate tolerant (Kishore et al. 1988). Variants of the wild-type EPSPS enzyme have been isolated which are glyphosate tolerant as a result of alterations in the EPSPS amino acid coding sequence (Kishore and Shah, 1988; Schulz et al., 1984; Sost et al., 1984; Kishore et al., 1986). These variants typically have a higher  $K_i$  for 5 glyphosate than the wild-type EPSPS enzyme which confers the glyphosate tolerant phenotype, but these variants are also characterized by a high  $K_m$  for PEP which makes the enzyme kinetically less efficient (Kishore and Shah, 1988; Sost et al., 1984; Schulz et al., 1984; Kishore et al., 1986); Sost and Amrhein, 1990). 10 For example, the apparent  $K_m$  for PEP and the apparent  $K_i$  for glyphosate for the native EPSPS from *E. coli* are 10  $\mu\text{M}$  and 0.5  $\mu\text{M}$  while for a glyphosate tolerant isolate having a single amino acid substitution of an alanine for the glycine at position 96 these values are 220  $\mu\text{M}$  and 4.0 mM, respectively. A number of 15 glyphosate tolerant plant variant EPSPS genes have been constructed by mutagenesis. Again, the glyphosate tolerant EPSPS was impaired due to an increase in the  $K_m$  for PEP and a slight reduction of the  $V_{max}$  of the native plant enzyme (Kishore and Shah, 1988) thereby lowering the catalytic efficiency ( $V_{max}/K_m$ ) of the enzyme. Since the kinetic constants of the 20 variant enzymes are impaired with respect to PEP, it has been proposed that high levels of overproduction of the variant enzyme, 40-80 fold, would be required to maintain normal catalytic activity in the presence of glyphosate (Kishore et al., 1988).

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While such variant EPSP synthases have proved useful in obtaining transgenic plants tolerant to glyphosate, it would be increasingly beneficial to obtain an EPSP synthase that is highly glyphosate tolerant while still kinetically efficient such that 5 the amount of the glyphosate tolerant EPSPS needed to be produced to maintain normal catalytic activity in the plant is reduced or that improved tolerance be obtained with the same expression level.

Previous studies have shown that EPSPS enzymes from different sources vary widely with respect to their degree of 10 sensitivity to inhibition by glyphosate. A study of plant and bacterial EPSPS enzyme activity as a function of glyphosate concentration showed that there was a very wide range in the degree of sensitivity to glyphosate. The degree of sensitivity showed no correlation with any genus or species tested (Schulz et 15 al., 1985). Insensitivity to glyphosate inhibition of the activity of the EPSPS from the *Pseudomonas* sp. PG2982 has also been reported but with no details of the studies (Fitzgibbon, 1988). In general, while such natural tolerance has been reported, there is no report suggesting the kinetic superiority of the naturally occurring 20 bacterial glyphosate tolerant EPSPS enzymes over those of mutated EPSPS enzymes nor have any of the genes been characterized. Similarly, there are no reports on the expression of naturally glyphosate tolerant EPSPS enzymes in plants to confer glyphosate tolerance.

25

#### SUMMARY OF THE INVENTION

A DNA molecule comprising DNA encoding a kinetically efficient, glyphosate tolerant EPSP synthase is 30 present. The EPSP synthases of the present invention reduce the amount of overproduction of the EPSPS enzyme in a transgenic

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- plant necessary for the enzyme to maintain catalytic activity while still conferring glyphosate tolerance. This and other EPSP synthases described herein represent a new class of EPSPS enzymes, referred to hereinafter as Class II EPSPS enzymes.
- 5 Class II EPSPS enzymes share little homology to known bacterial or plant EPSPS enzymes and exhibit tolerance to glyphosate while maintaining suitable  $K_m$  (PEP) ranges. Suitable ranges of  $K_m$  (PEP) for EPSPS for enzymes of the present invention are between 1-150  $\mu\text{M}$ , with a more preferred range of between 1-35  $\mu\text{M}$ , and a 10 most preferred range between 2-25  $\mu\text{M}$ . These kinetic constants are determined under the assay conditions specified hereinafter. The  $V_{\max}$  of the enzyme should preferably be at least 15% of the uninhibited plant enzyme and more preferably greater than 25%. An EPSPS of the present invention preferably has a  $K_i$  for 15 glyphosate range of between 25-10000  $\mu\text{M}$ . The  $K_i/K_m$  ratio should be between 3-500, and more preferably between 6-250. The  $V_{\max}$  should preferably be in the range of 2-100 units/mg ( $\mu\text{moles}/\text{minute} \cdot \text{mg}$  at 25°C) and the  $K_m$  for shikimate-3-phosphate 20 should preferably be in the range of 0.1 to 50  $\mu\text{M}$ .
- Genes coding for Class II EPSPS enzymes have been isolated from three (3) different bacteria: *Agrobacterium tumefaciens* sp. strain CP4, *Achromobacter* sp. strain LBAA, and *Pseudomonas* sp. strain PG2982. The LBAA and PG2982 Class II 25 EPSPS genes have been determined to be identical and the proteins encoded by these two genes are very similar to the CP4 protein and share approximately 84% amino acid identity with it. Class II EPSPS enzymes can be readily distinguished from Class I EPSPS's by their inability to react with polyclonal antibodies prepared from 30 Class I EPSPS enzymes under conditions where other Class I EPSPS enzymes would readily react with the Class I antibodies.

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Other Class II EPSPS enzymes can be readily isolated and identified by utilizing a nucleic acid probe from one of the Class II EPSPS genes disclosed herein using standard hybridization techniques. Such a probe from the CP4 strain has 5 been prepared and utilized to isolate the Class II EPSPS genes from strains LBAA and PG2982. These genes may also be adapted for enhanced expression in plants by known methodology. Such a probe has also been used to identify homologous genes in bacteria isolated *de novo* from soil.

10 The Class II EPSPS enzymes are preferably fused to a chloroplast transit peptide (CTP) to target the protein to the chloroplasts of the plant into which it may be introduced. Chimeric genes encoding this CTP-Class II EPSPS fusion protein may be prepared with an appropriate promoter and 3' 15 polyadenylation site for introduction into a desired plant by standard methods.

Therefore, in one aspect, the present invention provides a new class of EPSP synthases that exhibit a low  $K_m$  for phosphoenolpyruvate (PEP), a high  $V_{max}/K_m$  ratio, and a high  $K_i$  20 for glyphosate such that when introduced into a plant, the plant is made glyphosate tolerant such that the catalytic activity of the enzyme and plant metabolism are maintained in a substantially normal state. For purposes of this discussion, a highly efficient EPSPS refers to its efficiency in the presence of glyphosate.

25 In another aspect of the present invention, a double-stranded DNA molecule comprising DNA encoding a Class II EPSPS enzyme is disclosed. A Class II EPSPS enzyme DNA sequence is disclosed from three sources: *Agrobacterium* sp. strain designated CP4, *Achromobacter* sp. strain LBAA and 30 *Pseudomonas* sp. strain PG2982.

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In a further aspect of the present invention, a nucleic acid probe from an EPSPS Class II gene is presented that is suitable for use in screening for Class II EPSPS genes in other sources by assaying for the ability of a DNA sequence from the 5 other source to hybridize to the probe.

In yet another aspect of the present invention, transgenic plants and transformed plant cells are disclosed that are made glyphosate tolerant by the introduction of a Class II EPSPS gene into the plant's genome.

10 In a still further aspect of the invention, a recombinant, double-stranded DNA molecule comprising in sequence:

- a) a promoter which functions in plant cells to cause the production of an RNA sequence;
- 15 b) a structural DNA sequence that causes the production of an RNA sequence which encodes a Class II EPSPS enzyme; and
- c) a 3' nontranslated region which functions in plant cells to cause the addition of a stretch of polyadenyl 20 nucleotides to the 3' end of the RNA sequence

where the promoter is heterologous with respect to the structural DNA sequence and adapted to cause sufficient expression of the fusion polypeptide to enhance the glyphosate tolerance of a plant cell transformed with said DNA molecule.

25 In still another aspect of the present invention, a method for selectively controlling weeds in a crop field is presented by planting crop seeds or crop plants transformed with a Class II EPSPS gene to confer glyphosate tolerance to the plants which allows for glyphosate containing herbicides to be applied to the crop to selectively kill the glyphosate sensitive weeds but not the

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Other and further objects, advantages and aspects of the invention will become apparent from the accompanying drawing figures and the description of the invention.

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### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the DNA sequence (SEQ ID NO:1) for the full-length promoter of figwort mosaic virus (FMV35S).

10 Figure 2 shows the cosmid cloning vector pMON17020. Figure 3 shows the structural DNA sequence (SEQ ID NO:2) for the Class II EPSPS gene from bacterial isolate *Agrobacterium* sp. strain CP4 and the deduced amino acid sequence (SEQ ID NO:3). 1482 ( 455 a.a.)

15 Figure 4 shows the structural DNA sequence (SEQ ID NO:4) for the Class II EPSPS gene from the bacterial isolate *Achromobacter* sp. strain LBAA and the deduced amino acid sequence (SEQ ID NO:5). 1673 ( 449 a.a.)

20 Figure 5 shows the structural DNA sequence (SEQ ID NO:6) for the Class II EPSPS gene from the bacterial isolate *Pseudomonas* sp. strain PG2982 and the deduced amino acid sequence (SEQ ID NO:7). 1500 ( 444 a.a.)

Figure 6 shows the Bestfit comparison of the *E. coli* EPSPS amino acid sequence (SEQ ID NO:8) with that for the CP4 EPSPS (SEQ ID NO:3). 423 a.a.

25 Figure 7 shows the Bestfit comparison of the CP4 EPSPS amino acid sequence (SEQ ID NO:3) with that for the LBAA EPSPS (SEQ ID NO:5).

Figure 8 shows the structural DNA sequence (SEQ ID NO:9) for the synthetic CP4 Class II EPSPS gene. 1377

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Figure 9 shows the DNA sequence (SEQ ID NO:10) of the chloroplast transit peptide (CTP) and encoded amino acid sequence (SEQ ID NO:11) derived from the *Arabidopsis thaliana* EPSPS CTP and containing a *SphI* restriction site at the 5 chloroplast processing site, hereinafter referred to as CTP2.

Figure 10 shows the DNA sequence (SEQ ID NO:12) of the chloroplast transit peptide and encoded amino acid sequence (SEQ ID NO:13) derived from the *Arabidopsis thaliana* EPSPS gene and containing an *EcoRI* restriction site within the mature region 10 of the EPSPS, hereinafter referred to as CTP3.

Figure 11 shows the DNA sequence (SEQ ID NO:14) of the chloroplast transit peptide and encoded amino acid sequence (SEQ ID NO:15) derived from the *Petunia hybrida* EPSPS CTP and containing a *SphI* restriction site at the chloroplast processing site 15 and in which the amino acids at the processing site are changed to -Cys-Met-, hereinafter referred to as CTP4.

Figure 12 shows the DNA sequence (SEQ ID NO:16) of the chloroplast transit peptide and encoded amino acid sequence (SEQ ID NO:17) derived from the *Petunia hybrida* EPSPS gene with 20 the naturally occurring *EcoRI* site in the mature region of the EPSPS gene, hereinafter referred to as CTP5.

Figure 13 shows a plasmid map of CP4 plant transformation/ expression vector pMON17110.

Figure 14 shows a plasmid map of CP4 synthetic 25 EPSPS gene plant transformation/ expression vector pMON17131.

Figure 15 shows a plasmid map of CP4 EPSPS free DNA plant transformation expression vector pMON13640.

Figure 16 shows a plasmid map of CP4 plant transformation/direct selection vector pMON17227.

30 Figure 17 shows a plasmid map of CP4 plant transformation/ expression vector pMON19653.

318 ( )

77 a.a.

402 ( )

105 a.a.

233 ( )

73 a.a.

352 ( )

101 a.a.

STATEMENT OF THE INVENTION

The expression of a plant gene which exists in double-stranded DNA form involves synthesis of messenger RNA (mRNA) from one strand of the DNA by RNA polymerase enzyme, and the subsequent processing of the mRNA primary transcript inside the nucleus. This processing involves a 3' non-translated region which adds polyadenylate nucleotides to the 3' end of the RNA.

Transcription of DNA into mRNA is regulated by a region of DNA usually referred to as the "promoter." The promoter region contains a sequence of bases that signals RNA polymerase to associate with the DNA, and to initiate the transcription into mRNA using one of the DNA strands as a template to make a corresponding complementary strand of RNA.

A number of promoters which are active in plant cells have been described in the literature. These include the nopaline synthase (NOS) and octopine synthase (OCS) promoters (which are carried on tumor-inducing plasmids of *Agrobacterium tumefaciens*), the cauliflower mosaic virus (CaMV) 19S and 35S promoters, the light-inducible promoter from the small subunit of ribulose bis-phosphate carboxylase (ssRUBISCO, a very abundant plant polypeptide) and the full-length transcript promoter from the figwort mosaic virus (FMV35S). All of these promoters have been used to create various types of DNA constructs which have been expressed in plants; see, e.g., PCT publication WO 84/02913 (Rogers et al., Monsanto).

Promoters which are known or are found to cause transcription of DNA in plant cells can be used in the present invention. Such promoters may be obtained from a variety of sources such as plants and plant DNA viruses and include, but

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are not limited to, the CaMV35S and FMV35S promoters and promoters isolated from plant genes such as ssRUBISCO genes. As described below, it is preferred that the particular promoter selected should be capable of causing sufficient expression to 5 result in the production of an effective amount of a Class II EPSPS to render the plant substantially tolerant to glyphosate herbicides. The amount of Class II EPSPS needed to induce the desired tolerance may vary with the plant species. It is preferred that the promoters utilized have relatively high expression in all 10 meristematic tissues in addition to other tissues inasmuch as it is now known that glyphosate is translocated and accumulated in this type of plant tissue. Alternatively, a combination of chimeric genes can be used to cumulatively result in the necessary overall 15 expression level of the selected Class II EPSPS enzyme to result in the glyphosate tolerant phenotype.

The mRNA produced by a DNA construct of the present invention also contains a 5' non-translated leader sequence. This sequence can be derived from the promoter selected to express the gene, and can be specifically modified so as 20 to increase translation of the mRNA. The 5' non-translated regions can also be obtained from viral RNAs, from suitable eukaryotic genes, or from a synthetic gene sequence. The present invention is not limited to constructs, as presented in the following examples, wherein the non-translated region is derived from both 25 the 5' non-translated sequence that accompanies the promoter sequence and part of the 5' non-translated region of the virus coat protein gene. Rather, the non-translated leader sequence can be derived from an unrelated promoter or coding sequence as discussed above.

30 A preferred promoter for use in the present invention is the full length transcript (SEQ ID NO:1) promoter from the

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figwort mosaic virus (FMV35S) which functions as a strong and uniform promoter with particularly good expression in meristematic tissue for chimeric genes inserted into plants, particularly dicotyledons. The resulting transgenic plant in  
5 general expresses the protein encoded by the inserted gene at a higher and more uniform level throughout the tissues and cells of the transformed plant than the same gene driven by an enhanced CaMV35S promoter. Referring to Figure 1, the DNA sequence (SEQ ID NO:1) of the FMV35S promoter is located between  
10 nucleotides 6368 and 6930 of the FMV genome. A 5' non-translated leader sequence is preferably coupled with the promoter. The leader sequence can be from the FMV35S genome itself or can be from a source other than FMV35S.

The 3' non-translated region of the chimeric plant  
15 gene contains a polyadenylation signal which functions in plants to cause the addition of polyadenylate nucleotides to the 3' end of the viral RNA. Examples of suitable 3' regions are (1) the 3' transcribed, non-translated regions containing the polyadenylated signal of *Agrobacterium* tumor-inducing (Ti)  
20 plasmid genes, such as the nopaline synthase (NOS) gene, and (2) plant genes like the soybean storage protein genes and the small subunit of the ribulose-1,5-bisphosphate carboxylase (ssRUBISCO) gene. An example of a preferred 3' region is that from the ssRUBISCO gene from pea (E9), described in greater detail below.

25 The DNA constructs of the present invention also contain a structural coding sequence in double-stranded DNA form which encodes a glyphosate tolerant, highly efficient Class II EPSPS enzyme.

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Identification of glyphosate tolerant, highly efficient EPSPS enzymes

In an attempt to identify and isolate glyphosate tolerant, highly efficient EPSPS enzymes, kinetic analysis of the 5 EPSPS enzymes from a number of bacteria exhibiting tolerance to glyphosate or that had been isolated from suitable sources was undertaken. It was discovered that in some cases the EPSPS enzymes showed no tolerance to inhibition by glyphosate and it was concluded that the tolerance phenotype of the bacterium was 10 due to an impermeability to glyphosate or other factors. In a number of cases, however, microorganisms were identified whose EPSPS enzyme showed a greater degree of tolerance to inhibition by glyphosate and that displayed a low  $K_m$  for PEP when compared to that previously reported for other microbial and plant sources. 15 The EPSPS enzymes from these microorganisms were then subjected to further study and analysis.

Table I displays the data obtained for the EPSPS enzymes identified and isolated as a result of the above described analysis. Table I includes data for three identified Class II EPSPS 20 enzymes that were observed to have a high tolerance to inhibition to glyphosate and a low  $K_m$  for PEP as well as data for the native Petunia EPSPS and a glyphosate tolerant variant of the Petunia EPSPS referred to as GA101. The GA101 variant is so named because it exhibits the substitution of an alanine residue for a 25 glycine residue at position 101 (with respect to Petunia) in the invariant region. When the change introduced into the Petunia EPSPS (GA101) was introduced into a number of other EPSPS enzymes, similar changes in kinetics were observed, an elevation of the  $K_m$  for glyphosate and of the  $K_m$  for PEP.

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**Table I Kinetic characterization of EPSPS enzymes**

5	ENZYME SOURCE	K <sub>m</sub> PEP (μM)	K <sub>i</sub> Glyphosate (μM)	K <sub>i</sub> /K <sub>m</sub>
	Petunia	5	0.4	0.08
	Petunia GA101	200	2000	10
	PG2982	2.1-3.1 <sup>1</sup>	25-82	~8-40
10	LBAA	~7.3-8 <sup>2</sup>	60 (est)	~7.9
	CP4	12 <sup>3</sup>	2720	227

1 Range of PEP tested = 1-40 μM .

2 Range of PEP tested = 5-80 μM

3 Range of PEP tested = 1.5-40 μM

15       The *Agrobacterium* sp. strain CP4 was initially identified by its ability to grow on glyphosate as a carbon source (10 mM) in the presence of 1 mM phosphate. The strain CP4 was identified from a collection obtained from a fixed-bed immobilized cell column that employed Mannville R-635 diatomaceous earth beads. The column had been run for three months on a waste-water feed from a glyphosate production plant. The column contained 50 mg/ml glyphosate and NH<sub>3</sub> as NH<sub>4</sub>Cl. Total organic carbon was 300 mg/ml and BOD's (Biological Oxygen Demand - a measure of "soft" carbon availability) were less than 30 mg/ml.

20       This treatment column has been described (H itkamp et al., 1990). Dworkin-Foster minimal salts medium containing glyphosate at 10 mM and with phosphate at 1 mM was used to select for microbes from a wash of this column that were capable of growing on glyphosate as sole carbon source. Dworkin-Foster minimal

25       medium was prepared by combining in 1 liter (with autoclaved

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H<sub>2</sub>O), 1 ml each of A, B and C and 10 ml of D (as per below) and thiamine HCl (5 mg).

A. D-F Salts (1000X stock; per 100 ml; autoclaved):

5	H <sub>3</sub> BO <sub>3</sub>	1 mg
	MnSO <sub>4</sub> .7H <sub>2</sub> O	1 mg
	ZnSO <sub>4</sub> .7H <sub>2</sub> O	12.5 mg
	CuSO <sub>4</sub> .5H <sub>2</sub> O	8 mg
10	NaMoO <sub>3</sub> .3H <sub>2</sub> O	1.7 mg

B. FeSO<sub>4</sub>.7H<sub>2</sub>O (1000X stock; per 100 ml; autoclaved)

0.1 g

15 C. MgSO<sub>4</sub>.7H<sub>2</sub>O (1000X stock; per 100 ml; autoclaved)

20 g

D. (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> (100X stock; per 100 ml; autoclaved)

20 g

20

Yeast Extract (YE; Difco) was added to a final concentration of 0.01 or 0.001%. The strain CP4 was also grown on media composed of D-F salts, amended as described above, containing glucose, gluconate and citrate (each at 0.1 %) as carb n sources and with inorganic phosphate (0.2 - 1.0 mM) as th ph spherous source.

Other Class II EPSPS containing microorganisms were identified as *Achromobacter* sp. strain LBAA, which was from a collection of bacteria previously described (Hallas et al., 30 1988) and *Pseudomonas* sp. strain PG2982 which has been

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described in the literature (Moore et al. 1983; Fitzgibbon 1988). It had been reported previously, from measurements in crude lysates, that the EPSPS enzyme from strain PG2982 was less sensitive to inhibition to glyphosate than that of *E. coli*, but there 5 has been no report of the details of this lack of sensitivity and there has been no report on the  $K_m$  for PEP for this enzyme or of the DNA sequence for the gene for this enzyme (Fitzgibbon, 1988; Fitzgibbon and Braymer, 1990).

10 **Relationship of the Class II EPSPS to those previously studied**

All EPSPS proteins studied to date have shown a remarkable degree of homology. For example, bacterial and plant EPSPS's are about 54% identical and with similarity as high as 80%. Within bacterial EPSPS's and plant EPSPS's themselves the 15 degree of identity and similarity is much greater (see Table II).

**Table II Comparison between exemplary Class I EPSPS protein sequences<sup>1</sup>**

	<u>similarity</u>	<u>identity</u>
<i>E. coli</i> vs. <i>S. typhimurium</i>	93.0	88.3
<i>P. hybrida</i> vs. <i>E. coli</i>	71.9	54.5
<i>P. hybrida</i> vs. Tomato	92.8	88.2

25 <sup>1</sup> The EPSPS sequences compared here were obtained from the following references: *E. coli*, Rogers et al., 1983; *S. typhimurium*, Stalker et al., 1985; *Petunia hybrida*, Shah et al., 1986; and Tomato, Gasser et al., 1988.

30 When crude extracts of CP4 and LBAA bacteria (50 µg protein) were probed using rabbit anti-EPSPS antibody (Padgette et

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al. 1987) to the Petunia EPSPS protein in a Western analysis, no positive signal could be detected, even with extended exposure times (Protein A -  $^{125}$ I development system) and under conditions where the control EPSPS (Petunia EPSPS, 20 ng; a Class I EPSPS) was readily detected. The presence of EPSPS activity in these extracts was confirmed by enzyme assay. This surprising result, indicating a lack of similarity between the EPSPS's from these bacterial isolates and those previously studied, coupled with the combination of a low  $K_m$  for PEP and a high  $K_i$  for glyphosate, illustrates that these new EPSPS enzymes are different from known EPSPS enzymes (now referred to as Class I EPSPS).

#### Glyphosate Tolerant Enzymes in Microbial Isolates

For clarity and brevity of disclosure, the following description of the isolation of genes encoding Class II EPSPS enzymes is directed to the isolation of such a gene from a bacterial isolate. Those skilled in the art will recognize that the same or similar strategy can be utilized to isolate such genes from other microbial isolates, plant or fungal sources.

20

#### Cloning of the *Agrobacterium* sp. strain CP4 EPSPS Gene(s) in *E. coli*

Having established the existence of a suitable EPSPS in *Agrobacterium* sp. strain CP4, two parallel approaches were undertaken to clone the gene: cloning based on the expected phenotype for a glyphosate tolerant EPSPS; and purification of the enzyme to provide material to raise antibodies and to obtain amino acid sequences from the protein to facilitate the verification of clones. Cloning and genetic techniques, unless otherwise indicated, are generally those described in Maniatis et al., 1982 or

Sambrook et al., 1987. The cloning strategy was as follows: introduction of a cosmid bank of strain *Agrobacterium* sp. strain CP4 into *E. coli* and selection for the EPSPS gene by selection for growth on inhibitory concentrations of glyphosate.

5 Chromosomal DNA was prepared from strain *Agrobacterium* sp. strain CP4 as follows: The cell pellet from a 200 ml L-Broth (Miller, 1972), late log phase culture of *Agrobacterium* sp. strain CP4 was resuspended in 10 ml of Solution I; 50 mM Glucose, 10 mM EDTA, 25 mM Tris -CL pH 8.0 (Birnboim and Doly, 1979). SDS was added to a final concentration  
10 of 1% and the suspension was subjected to three freeze-thaw cycles, each consisting of immersion in dry ice for 15 minutes and in water at 70°C for 10 minutes. The lysate was then extracted four times with equal volumes of phenol:chloroform (1:1; phenol  
15 saturated with TE; TE = 10 mM Tris pH8.0; 1.0 mM EDTA) and the phases separated by centrifugation (15000g; 10 minutes). The ethanol-precipitable material was pelleted from the supernatant by brief centrifugation (8000g; 5 minutes) following addition of two  
20 volumes of ethanol. The pellet was resuspended in 5 ml TE and dialyzed for 16 hours at 4°C against 2 liters TE. This preparation yielded a 5 ml DNA solution of 552 µg/ml.

Partially-restricted DNA was prepared as follows. Three 100 µg aliquot samples of CP4 DNA were treated for 1 hour at 37°C with restriction endonuclease *Hind*III at rates of 4, 2 and 1 enzyme unit/µg DNA, respectively. The DNA samples were pooled, made 0.25 mM with EDTA and extracted with an equal volume of phenol:chloroform. Following the addition of sodium acetate and ethanol, the DNA was precipitated with two volumes of ethanol and pelleted by centrifugation (12000 g; 10 minutes). The dried DNA pellet was resuspended in 500 µl TE and layered on a 10-40% Sucrose gradient (in 5% increments of 5.5 ml each) in 0.5 M

NaCl, 50 mM Tris pH8.0, 5 mM EDTA. Following centrifugation for 20 hours at 26,000 rpm in a SW28 rotor, the tubes were punctured and ~1.5 ml fractions collected. Samples (20 µl) of each second fraction were run on 0.7% agarose gel and the size of the DNA determined by comparison with linearized lambda DNA and *Hind*III-digested lambda DNA standards. Fractions containing DNA of 25-35 kb fragments were pooled, desalting on AMICON10 columns (7000 rpm; 20°C; 45 minutes) and concentrated by precipitation. This procedure yielded 15 µg of CP4 DNA of the required size. A cosmid bank was constructed using the vector pMON17020. This vector, a map of which is presented in Figure 2, is based on the pBR327 replicon and contains the spectinomycin/streptomycin (*Sp<sup>r</sup>;spc*) resistance gene from Tn7 (Fling et al., 1985), the chloramphenicol resistance gene (*Cm<sup>r</sup>;cat*) from Tn9 (Alton et al., 1979), the gene10 promoter region from phage T7 (Dunn et al., 1983), and the 1.6 kb *Bgl*II phage lambda cos fragment from pHC79 (Hohn and Collins, 1980). A number of cloning sites are located downstream of the *cat* gene. Since the predominant block to the expression of genes from other microbial sources in *E. coli* appears to be at the level of transcription, the use of the T7 promoter and supplying the T7 polymerase *in trans* from the pGP1-2 plasmid (Tabor and Richardson, 1985), enables the expression of large DNA segments of foreign DNA, even those containing RNA polymerase transcription termination sequences.

The expression of the *spc* gene is impaired by transcription from the T7 promoter such that only *Cm<sup>r</sup>* can be selected in strains containing pGP1-2. The use of antibiotic resistances such as *Cm* resistance which do not employ a membrane component is preferred due to the observation that high level expression of resistance genes that involve a membrane component, i.e.  $\beta$ -lactamase and Amp resistance, give rise to a glyphosate tolerant

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phenotype. Presumably, this is due to the exclusion of glyphosate from the cell by the membrane localized resistance protein. It is also preferred that the selectable marker be oriented in the same direction as the T7 promoter.

5        The vector was then cut with *Hind*III and treated with calf alkaline phosphatase (CAP) in preparation for cloning. Vector and target sequences were ligated by combining the following:

10	Vector DNA ( <i>Hind</i> III/CAP)	3 µg
	Size fractionated CP4 <i>Hind</i> III fragments	1.5 µg
	10X ligation buffer	2.2 µl
	T4 DNA ligase (New England Biolabs) (400 U/µl)	1.0 µl

15      and adding H<sub>2</sub>O to 22.0 µl. This mixture was incubated for 18 hours at 16°C. 10X ligation buffer is 250 mM Tris-HCl, pH 8.0; 100 mM MgCl<sub>2</sub>; 100 mM Dithiothreitol; 2 mM Spermidine. The ligated DNA (5 µl) was packaged into lambda phage particles (Stratagene; Gigapack Gold) using the manufacturer's procedure.

20      A sample (200 µl) of *E. coli* HB101 (Boyer and Rolland-Dussoix, 1973) containing the T7 polymerase expression plasmid pGP1-2 (Tabor and Richardson, 1985) and grown overnight in L-Broth (with maltose at 0.2% and kanamycin at 50 µg/ml) was infected with 50 µl of the packaged DNA.

25      Transformants were selected at 30°C on M9 (Miller, 1972) agar containing kanamycin (50 µg/ml), chl ramphenicol (25 µg/ml), L-proline (50 µg/ml), L-leucin (50 µg/ml) and B1 (5 µg/ml), and with glyphosate at 3.0 mM. Aliquots samples were also plated on the same media lacking glyphosate to titer the packaged cosmids.

30      Grown transformants were isolated on this latter medium at a

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rate of  $\sim 5 \times 10^5$  per  $\mu\text{g}$  CP4 *Hind*III DNA after 3 days at 30°C. Colonies arose on the glyphosate agar from day 3 until day 15 with a final rate of  $\sim 1$  per 200 cosmids. DNA was prepared from 14 glyphosate tolerant clones and, following verification of this 5 phenotype, was transformed into *E. coli* GB100/pGP1-2 (*E. coli* GB100 is an *aroA* derivative of MM294 [Talmadge and Gilbert, 1980]) and tested for complementation for growth in the absence of added aromatic amino acids and aminobenzoic acids. Other *aroA* strains such as SR481 (Bachman et al. 1980; Padgett et al., 1987), 10 could be used and would be suitable for this experiment. The use of GB100 is merely exemplary and should not be viewed in a limiting sense. This *aroA* strain usually requires that growth media be supplemented with L-phenylalanine, L-tyrosine and L-tryptophan each at 100  $\mu\text{g}/\text{ml}$  and with para-hydroxybenzoic 15 acid, 2,3-dihydroxybenzoic acid and para-aminobenzoic acid each at 5  $\mu\text{g}/\text{ml}$  for growth in minimal media. Of the fourteen cosmids tested only one showed complementation of the *aroA*- phenotype. Transformants of this cosmid, pMON17076, showed weak but uniform growth on the unsupplemented minimal media after 10 20 days.

The proteins encoded by the cosmids were determined *in vivo* using a T7 expression system (Tabor and Richardson, 1985). Cultures of *E. coli* containing pGP1-2 (Tabor and Richardson, 1985) and test and control cosmids were grown at 25 30°C in L-broth (2 ml) with chloramphenicol and kanamycin (25 and 50  $\mu\text{g}/\text{ml}$ , respectively) to a Klett reading of  $\sim 50$ . An aliquot was removed and the cells collected by centrifugation, washed with M9 salts (Miller, 1972) and resuspended in 1 ml M9 medium containing glucose at 0.2%, thiamine at 20  $\mu\text{g}/\text{ml}$  and containing 30 the 18 amino acids at 0.01% (minus cysteine and methionine). Following incubation at 30°C for 90 minutes, the cultures were

transferred to a 42°C water bath and held there for 15 minutes. Rifampicin (Sigma) was added to 200 µg/ml and the cultures held at 42°C for 10 additional minutes and then transferred to 30°C for 20 minutes. Samples were pulsed with 10 µCi of  $^{35}\text{S}$ -methionine  
5 for 5 minutes at 30°C. The cells were collected by centrifugation and suspended in 60-120 µl cracking buffer (60 mM Tris-HCl 6.8, 1% SDS, 1% 2-mercaptoethanol, 10% glycerol, 0.01% bromophenol blue). Aliquot samples were electrophoresed on 12.5% SDS-PAGE and following soaking for 60 minutes in 10 volumes of Acetic  
10 Acid-Methanol-water (10:30:60), the gel was soaked in ENLIGHTNING™ (DUPONT) following manufacturer's directions, dried, and exposed at -70°C to X-Ray film. Proteins of about 45 kd in size, labeled with  $^{35}\text{S}$ -methionine, were detected in number of the cosmid, including pMON17076.

15

Purification of EPSPS from *Agrobacterium* sp. strain CP4

All protein purification procedures were carried out at 3-5°C. EPSPS enzyme assays were performed using either the phosphate release or radioactive HPLC method, as previously described in Padgett et al. 1987, using 1 mM phosphoenol pyruvate (PEP, Boehringer) and 2 mM shikimate-3-phosphate (S3P) substrate concentrations. For radioactive HPLC assays,  $^{14}\text{C}$ -PEP (Amersham) was utilized. S3P was synthesized as previously described in Wibbenmeyer et al. 1988. N-terminal 20 amino acid sequencing was performed by loading samples onto a Polybrene precycled filter in aliquots while drying. Automated Edman degradation chemistry was used to determine the N-terminal protein sequence, using an Applied Biosystems Model 25 470A gas phase sequencer (Hunkapiller et al. 1983) with an  
25 Applied Biosystems 120A PTH analyzer.  
30

Five 10-litre fermentations were carried out on a spontaneous "smooth" isolate of strain CP4 that displayed less clumping when grown in liquid culture. This reduced clumping and smooth colony morphology may be due to reduced polysaccharide production by this isolate. In the following section dealing with the purification of the EPSPS enzyme, CP4 refers to the "smooth" isolate - CP4-S1. The cells from the three batches showing the highest specific activities were pooled. Cell paste of *Agrobacterium* sp. CP4 (300 g) was washed twice with 0.5 L of 0.9% saline and collected by centrifugation (30 minutes, 8000 rpm in a GS3 Sorvall rotor). The cell pellet was suspended in 0.9 L extraction buffer (100 mM TrisCl, 1 mM EDTA, 1 mM BAM (Benzamidine), 5 mM DTT, 10% glycerol, pH 7.5) and lysed by 2 passes through a Manton Gaulin cell. The resulting solution was centrifuged (30 minutes, 8000 rpm) and the supernatant was treated with 0.21 L of 1.5% protamine sulfate (in 100 mM TrisCl, pH 7.5, 0.2% w/v final protamine sulfate concentration). After stirring for 1 hour, the mixture was centrifuged (50 minutes, 8000 rpm) and the resulting supernatant treated with solid ammonium sulfate to 40% saturation and stirred for 1 hour. After centrifugation (50 minutes, 8000 rpm), the resulting supernatant was treated with solid ammonium sulfate to 70% saturation, stirred for 50 minutes, and the insoluble protein was collected by centrifugation (1 hour, 8000 rpm). This 40-70% ammonium sulfate fraction was then dissolved in extraction buffer to give a final volume of 0.2 L, and dialyzed twice (Spectrum 10,000 MW cutoff dialysis tubing) against 2 L of extraction buffer for a total of 12 hours.

To the resulting dialyzed 40-70% ammonium sulfate fraction (0.29 L) was added solid ammonium sulfate to give a final concentration of 1 M. This material was loaded (2 ml/min) onto a

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column (5 cm x 15 cm, 295 ml) packed with phenyl Sepharose CL-4B (Pharmacia) resin equilibrated with extraction buffer containing 1 M ammonium sulfate, and washed with the same buffer (1.5 L, 2 ml/min). EPSPS was eluted with a linear gradient of extraction buffer going from 1 M to 0.00 M ammonium sulfate (total volume of 1.5 L, 2 ml/min). Fractions were collected (20 ml) and assayed for EPSPS activity by the phosphate release assay. The fractions with the highest EPSPS activity (fractions 36-50) were pooled and dialyzed against 3 x 2 L (18 hours) of 10 mM TrisCl, 25 mM KCl, 1 mM EDTA, 5 mM DTT, 10% glycerol, pH 7.8.

The dialyzed EPSPS extract (350 ml) was loaded (5 ml/min) onto a column (2.4 cm x 30 cm, 136 ml) packed with Q-Sepharose Fast Flow (Pharmacia) resin equilibrated with 10 mM TrisCl, 25 mM KCl, 5 mM DTT, 10% glycerol, pH 7.8 (Q Sepharose buffer), and washed with 1 L of the same buffer. EPSPS was eluted with a linear gradient of Q Sepharose buffer going from 0.025 M to 0.40 M KCl (total volume of 1.4 L, 5 ml/min). Fractions were collected (15 ml) and assayed for EPSPS activity by the phosphate release assay. The fractions with the highest EPSPS activity (fractions 47-60) were pooled and the protein was precipitated by adding solid ammonium sulfate to 80% saturation and stirring for 1 hour. The precipitated protein was collected by centrifugation (20 minutes, 12000 rpm in a GSA Sorvall rotor), dissolved in Q Sepharose buffer (total volume of 14 ml), and dialyzed against the same buffer (2 x 1 L, 18 hours).

The resulting dialyzed partially purified EPSPS extract (19 ml) was loaded (1.7 ml/min) onto a Mono Q 10/10 column (Pharmacia) equilibrated with Q Sepharose buffer, and washed with the same buffer (35 ml). EPSPS was eluted with a linear gradient of 0.025 M to 0.35 M KCl (total volume of 119 ml, 1.7 ml/min). Fractions were collected (1.7 ml) and assayed for EPSPS

activity by the phosphate release assay. The fractions with the highest EPSPS activity (fractions 30-37) were pooled (6 ml).

The Mono Q pool was made 1 M in ammonium sulfate by the addition of solid ammonium sulfate and 2 ml aliquots were 5 chromatographed on a Phenyl Superose 5/5 column (Pharmacia) equilibrated with 100 mM TrisCl, 5 mM DTT, 1 M ammonium sulfate, 10% glycerol, pH 7.5 (Phenyl Superose buffer). Samples were loaded (1 ml/min), washed with Phenyl Superose buffer (10 ml), and eluted with a linear gradient of Phenyl Superose buffer 10 going from 1 M to 0.00 M ammonium sulfate (total volume of 60 ml, 1 ml/min). Fractions were collected (1 ml) and assayed for EPSPS activity by the phosphate release assay. The fractions from each run with the highest EPSPS activity (fractions ~36-40) were pooled together (10 ml, 2.5 mg protein). For N-terminal amino 15 acid sequence determination, a portion of one fraction (#39 from run 1) was dialyzed against 50 mM NaHCO<sub>3</sub> (2 x 1 L). The resulting pure EPSPS sample (0.9 ml, 77 µg protein) was found to exhibit a single N-terminal amino acid sequence of: XH(G)ASSRPATARKSS(G)LX(G)(T)V(R)IPG(D)(K)(M) (SEQ ID NO:18).

In this and all amino acid sequences to follow, the standard single letter nomenclature is used. All peptide structures represented in the following description are shown in conventional format wherein the amino group at the N-terminus appears to the left and the carboxyl group at the C-terminus at the 20 right. Likewise, amin acid nomenclature for the naturally occurring amino acids found in protein is as follows: alanine (Ala;A), asparagine (Asn;N), aspartic acid (Asp;D), arginine (Arg;R), cysteine (Cys;C), glutamic acid (Glu;E), glutamine (Gln;Q), glycine (Gly;G), histidine (His;H), isoleucine (Ile;I), 25 leucin (Leu;L), lysine (Lys;K), methionine (M t;M), phenylalanine (Phe;F), proline (Pro;P), serine (Ser;S) threonine 30 (Thr;T), tyrosine (Tyr;Y) and valine (Val;V).

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(Thr;T), tryptophan (Trp;W), tyrosine (Tyr;Y), and valine (Val;V). An "X" is used when the amino acid residue is unknown and parentheses designate that an unambiguous assignment is not possible and the amino acid designation within the parentheses is 5 the most probable estimate based on known information.

The remaining Phenyl Superose EPSPS pool was dialyzed against 50 mM TrisCl, 2 mM DTT, 10 mM KCl, 10% glycerol, pH 7.5 (2 x 1 L). An aliquot (0.55 ml, 0.61 mg protein) was loaded (1 ml/min) onto a Mono Q 5/5 column (Pharmacia) 10 equilibrated with Q Sepharose buffer, washed with the same buffer (5 ml), and eluted with a linear gradient of Q Sepharose buffer going from 0-0.14 M KCl in 10 minutes, then holding at 0.14 M KCl (1 ml/min). Fractions were collected (1 ml) and assayed for EPSPS activity by the phosphate release assay and were subjected to 15 SDSPAGE (10-15%, Phast System, Pharmacia, with silver staining) to determine protein purity. Fractions exhibiting a single band of protein by SDS-PAGE (22-25, 222 µg) were pooled and dialyzed against 100 mM ammonium bicarbonate, pH 8.1 (2 x 1 L, 9 hours).

20

Trypsinolysis and peptide sequencing of Agrobacterium sp strain CP4 EPSPS

To the resulting pure *Agrobacterium* sp. strain CP4 EPSPS (111 µg) was added 3 µg of trypsin (Calbiochem), and the 25 trypsinolysis reaction was allowed to proceed for 16 hours at 37°C. The tryptic digest was then chromatographed (1ml/min) on a C18 reverse phase HPLC column (Vydac) as previously described in Padgett et al. 1988 for *E. coli* EPSPS. For all peptide purifications, 0.1% trifluoroacetic acid (TFA, Pierce) was designated buffer 30 "RP-A" and 0.1% TFA in acetonitrile was buffer "RP-B". The gradient used for elution of the trypsinized *Agrobacterium* sp. CP4

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EPSPS was: 0-8 minutes, 0% RP-B; 8-28 minutes, 0-15% RP-B; 28-40 minutes, 15-21% RP-B; 40-68 minutes, 21-49% RP-B; 68-72 minutes, 49-75% RP-B; 72-74 minutes, 75-100% RP-B. Fractions were collected (1 ml) and, based on the elution profile at 210 nm, at least 70 distinct peptides were produced from the trypsinized EPSPS. Fractions 40-70 were evaporated to dryness and redissolved in 150 µl each of 10% acetonitrile, 0.1% trifluoroacetic acid.

The fraction 61 peptide was further purified on the C18 column by the gradient: 0-5 minutes, 0% RP-B; 5-10 minutes, 0-38% RP-B; 10-30 minutes, 38-45% B. Fractions were collected based on the UV signal at 210 nm. A large peptide peak in fraction 24 eluted at 42% RP-B and was dried down, resuspended as described above, and rechromatographed on the C18 column with the gradient: 0-5 minutes, 0% RP-B; 5-12 min, 0-38% RP-B; 12-15 min, 38-39% RP-B; 15-18 minutes, 39% RP-B; 18-20 minutes, 39-41% RP-B; 20-24 minutes, 41% RP-B; 24-28 minutes, 42% RP-B. The peptide in fraction 25, eluting at 41% RP-B and designated peptide 61-24-25, was subjected to N-terminal amino acid sequencing, and the following sequence was determined:

APSM(I)(D)EYPILAV (SEQ ID NO:19).

The CP4 EPSPS fraction 53 tryptic peptide was further purified by C18 HPLC by the gradient 0% B (5 minutes), 0-30% B (5-17 minutes), 30-40% B (17-37 minutes). The peptide in fraction 28, 25 eluting at 34% B and designated peptide 53-28, was subjected to N-terminal amino acid sequencing, and the following sequence was determined:

ITGLLEGEDVINTGK (SEQ ID NO: 20).

In order to verify the CP4 EPSPS cosmid clone, a series of peptide probes were designed on the basis of the

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sequence of two of the tryptic sequences from the CP4 enzyme (Table III). The probe identified as MID was very low degeneracy and was used for initial screening. The probes identified as EDV-C and EDV-T were based on the same amino acid sequences 5 and differ in one position (underlined in Table III below) and were used as confirmatory probes, with a positive to be expected only from one of these two probes. In the oligonucleotides below, alternate acceptable nucleotides at a particular position are designated by a "/" such as A/C/T.

10 Table III Selected CP4 EPSPS peptide sequences and DNA probes

PEPTIDE 61-24-25 APSM(I)(D)EYPILAV (SEQ ID NO:19)

Probe MID; 17-mer; mixed probe; 24-fold degenerate

15 ATGATA/C/TGAC/TGAG/ATAC/TCC (SEQ ID NO:21)

PEPTIDE 53-28 ITGLLEGEDVINTGK (SEQ ID NO:20)

Probe EDV-C; 17-mer; mixed probe; 48-fold degenerate

GAA/GGAC/TGTA/C/G/TATA/C/TAACAC (SEQ ID NO:22)

Probe EDV-T; 17-mer; mixed probe; 48-fold degenerate

20 GAA/GGAC/TGTA/C/G/TATA/C/TAATAC (SEQ ID NO:23)

The probes were labeled using gamma- $^{32}$ P-ATP and polynucleotide kinase. DNA from fourteen of the cosmids described above was restricted with EcoRI, transferred to 25 membrane and probed with the oligonucleotide probes. The conditions used were as follows: prehybridization was carried out in 6X SSC, 10X Denhardt's for 2-18 hour periods at 60°C, and hybridization was for 48-72 hours in 6X SSC, 10X Denhardt's, 100  $\mu$ g/ml tRNA at 10°C below the T<sub>d</sub> for the probe. The T<sub>d</sub> of the probe 30 was approximated by the formula 2°C x (A+T) + 4°C x (G+C). The

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filters were then washed three times with 6X SSC for ten minutes each at room temperature, dried and autoradiographed. Using the MID probe, an ~9.9 kb fragment in the pMON17076 cosmid gave the only positive signal. This cosmid DNA was then probed with the EDV-C (SEQ ID NO:22) and EDV-T (SEQ ID NO:23) probes separately and again this ~9.9 kb band gave a signal and only with the EDV-T probe.

The combined data on the glyphosate tolerant phenotype, the complementation of the *E. coli* aroA- phenotype, the expression of a ~45 Kd protein, and the hybridization to two probes derived from the CP4 EPSPS amino acid sequence strongly suggested that the pMON17076 cosmid contained the EPSPS gene.

Localization and subcloning of the CP4 EPSPS gene

The CP4 EPSPS gene was further localized as follows: a number of additional Southern analyses were carried out on different restriction digests of pMON17076 using the MID (SEQ ID NO:21) and EDV-T (SEQ ID NO:23) probes separately. Based on these analyses and on subsequent detailed restriction mapping of the pBlueScript (Stratagene) subclones of the ~9.9 kb fragment from pMON17076, a 3.8 kb EcoRI-SalI fragment was identified to which both probes hybridized. This analysis also showed that MID (SEQ ID NO:21) and EDV-T (SEQ ID NO:23) probes hybridized to different sides of BamHI, ClaI, and SacII sites. This 3.8 kb fragment was cloned in both orientations in pBlueScript to form pMON17081 and pMON17082. The phenotypes imparted to *E. coli* by these clones were then determined. Glyphosate tolerance was determined following transformation into *E. coli* MM294 containing pGP1-2 (pBlueScript also contains a T7 promoter) on M9 agar media containing glyphosate at 3 mM. Both pMON17081 and pMON17082 showed glyphosate tolerant colonies at three days

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at 30°C at about half the size of the controls on the same media lacking glyphosate. This result suggested that the 3.8 kb fragment contained an intact EPSPS gene. The apparent lack of orientation-dependence of this phenotype could be explained by the presence of the T7 promoter at one side of the cloning sites and the lac promoter at the other. The *aroA* phenotype was determined in transformants of *E. coli* GB100 on M9 agar media lacking aromatic supplements. In this experiment, carried out with and without the *P<sub>lac</sub>* inducer IPTG, pMON17082 showed much greater growth than pMON17081, suggesting that the EPSPS gene was expressed from the *SacI* site towards the *EcoRI* site.

Nucleotide sequencing was begun from a number of restriction site ends, including the *BamHI* site discussed above. Sequences encoding protein sequences that closely matched the N-terminus protein sequence and that for the tryptic fragment 53-28 (SEQ ID NO:20) (the basis of the EDV-T probe) (SEQ ID NO:23) were localized to the *SacI* side of this *BamHI* site. These data provided conclusive evidence for the cloning of the CP4 EPSPS gene and for the direction of transcription of this gene. These data coupled with the restriction mapping data also indicated that the complete gene was located on an ~2.3 kb *XbaI* fragment and this fragment was subcloned into pBlueScript. The nucleotide sequence of almost 2 kb of this fragment was determined by a combination of sequencing from cloned restriction fragments and by the use of specific primers to extend the sequence. The nucleotide sequence of the CP4 EPSPS gene and flanking regions is shown in Figure 3 (SEQ ID NO:2). The sequence corresponding to peptide 61-24-25 (SEQ ID NO:19) was also located. The sequence was determined using both the Sequenase kit from IBI (International Biotechnologies Inc.) and the T7 sequencing /Deaza Kit from Pharmacia.

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That the cloned gene encoded the EPSPS activity purified from the *Agrobacterium* sp. strain CP4 was verified in the following manner: By a series of site directed mutageneses, *Bgl*II and *Nco*I sites were placed at the N-terminus with the fMet contained within the *Nco*I recognition sequence, the first internal *Nco*I site was removed (the second internal *Nco*I site was removed later), and a *Sac*I site was placed after the stop codons. At a later stage the internal *Not*I site was also removed by site-directed mutagenesis. The following list includes the primers for the site-directed mutagenesis (addition or removal of restriction sites) of the CP4 EPSPS gene. Mutagenesis was carried out by the procedures of Kunkel et al. (1987), essentially as described in Sambrook et al. (1989).

15 PRIMER BgNc (addition of *Bgl*II and *Nco*I sites to N-terminus)  
CGTGGATAGATCTAGGAAGACAAACCATGGCTCACGGTC  
(SEQ ID NO:24)

20 PRIMER Sph2 (addition of *Sph*I site to N-terminus)  
GGATAGATTAAGGAAGACGCGCATGCTTCACGGTGCAAGC  
AGCC (SEQ ID NO:25)

25 PRIMER S1 (addition of *Sac*I site immediately after stop codons)  
GGCTGCCTGATGAGCTCCACAATGCCATCGATGG  
(SEQ ID NO:26)

PRIMER N1 (removal of internal *Not*I recognition site)  
CGTCGCTCGTCGTGCGTGGCCGCCCTGACGGC  
(SEQ ID NO:27)

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PRIMER Nco1 (removal of first internal NcoI recognition site)

CGGGCAAGGCCATGCAGGCTATGGGCGCC (SEQ ID NO:28)

PRIMER Nco2 (removal of second internal NcoI recognition site)

5 CGGGCTGCCGCCTGACTATGGGCCTCGTCGG (SEQ ID NO:29)

This CP4 EPSPS gene was then cloned as a NcoI-BamHI N-terminal fragment plus a BamHI-SacI C-terminal fragment into a *PrecA-gene10L* expression vector similar to those described (Wong et al., 1988; Olins et al., 1988) to form pMON17101. The K<sub>m</sub> for PEP and the K<sub>i</sub> for glyphosate were determined for the EPSPS activity in crude lysates of pMON17101/GB100 transformants following induction with nalidixic acid (Wong et al., 1988) and found to be the same as that determined for the purified and crude enzyme preparations from *Agrobacterium* sp. strain CP4.

Characterization of the EPSPS gene from *Achromobacter* sp. strain LBAA and from *Pseudomonas* sp. strain PG2982

20 A cosmid bank of partially HindIII-restricted LBAA DNA was constructed in *E. coli* MM294 in the vector pHC79 (Hohn and Collins, 1980). This bank was probed with a full length CP4 EPSPS gene probe by colony hybridization and positive clones were identified at a rate of ~1 per 400 cosmids. The LBAA EPSPS gene was further localized in these cosmids by Southern analysis. The gene was located on an ~2.8 kb XbaI fragment and by a series of sequencing steps, both from restriction fragment ends and by using the oligonucleotide primers from the sequencing of the CP4 EPSPS gene, the nucleotide sequence of the LBAA EPSPS gene was completed and is presented in Figure 4 (SEQ ID NO:4).

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The EPSPS gene from PG2982 was also cloned. The EPSPS protein was purified, essentially as described for the CP4 enzyme, with the following differences: Following the Sepharose CL-4B column, the fractions with the highest EPSPS activity were 5 pooled and the protein precipitated by adding solid ammonium sulfate to 85% saturation and stirring for 1 hour. The precipitated protein was collected by centrifugation, resuspended in Q Sepharose buffer and following dialysis against the same buffer was loaded onto the column (as for the CP4 enzyme). After 10 purification on the Q Sepharose column, ~40 mg of protein in 100 mM Tris pH 7.8, 10% glycerol, 1 mM EDTA, 1 mM DTT, and 1 M ammonium sulfate, was loaded onto a Phenyl Superose (Pharmacia) column. The column was eluted at 1.0 ml/minutes 15 with a 40 ml gradient from 1.0 M to 0.00 M ammonium sulfate in the above buffer.

Approximately 1.0 mg of protein from the active fractions of the Phenyl Superose 10/10 column was loaded onto a Pharmacia Mono P 5/10 Chromatofocusing column with a flow rate of 0.75 ml/minutes. The starting buffer was 25 mM bis-Tris at 20 pH 6.3, and the column was eluted with 39 ml of Polybuffer 74, pH 4.0. Approximately 50 µg of the peak fraction from the Chromatofocusing column was dialyzed into 25 mM ammonium bicarbonate. This sample was then used to determine the N-terminal amino acid sequence.

25 The N-terminal sequence obtained was:

XHSASPKPATARRSE (where X = an unidentified residue) (SEQ ID NO:30). A number of degenerate oligonucleotide probes were designed based on this sequence and used to probe a library of PG2982 partial-*Hind*III DNA in the cosmid pHC79 30 (Hohn and Collins, 1980) by colony hybridization under nonstringent conditions. Final washing conditions were 15

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minutes with 1X SSC, 0.1% SDS at 55°C. One probe with the sequence GCGGTBGC<sub>S</sub>GGYTTSGG (where B = C, G, or T; S = C or G, and Y = C or T) (SEQ ID NO:31) identified a set of cosmid clones.

5       The cosmid set identified in this way was made up of cosmids of diverse *Hind*III fragments. However, when this set was probed with the CP4 EPSPS gene probe, a cosmid containing the PG2982 EPSPS gene was identified (designated as cosmid 9C1 originally and later as pMON20107). By a series of restriction  
10      mappings and Southern analysis this gene was localized to a ~2.8 kb *Xba*I fragment and the nucleotide sequence of this gene was determined. This DNA sequence (SEQ ID NO:6) is shown in Figure 5. There are no nucleotide differences between the EPSPS  
15      gene sequences from LBAA (SEQ ID NO:4) and PG2982 (SEQ ID NO:6). The kinetic parameters of the two enzymes are within the range of experimental error.

A gene from PG2982 that imparts glyphosate tolerance in *E. coli* has been sequenced (Fitzgibbon, 1988; Fitzgibbon and Braymer, 1990). The sequence of the PG2982 EPSPS  
20      Class II gene shows no homology to the previously reported sequence suggesting that the glyphosate tolerant phenotype of the previous work is not related to EPSPS.

#### Alternative Isolation Protocols for Other Class II EPSPS

##### 25 Structural Genes

A number of Class II genes have been isolated and described here. It is clear that the initial gene cloning, that of the gene from CP4, was difficult due to the low degree of similarity between the Class I and Class II enzymes and genes. The  
30      identification of the other genes however was greatly facilitated by the use of this first gene as a probe. In the cloning of the LBAA

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EPSPS gene, the CP4 gene probe allowed the rapid identification of cosmid clones and the localization of the intact gene to a small restriction fragment and some of the CP4 sequencing primers were also used to sequence the LBAA (and PG2982) EPSPS gene(s).

- 5 The CP4 gene probe was also used to confirm the PG2982 gene clone. The high degree of similarity of the Class II EPSPS genes may be used to identify and clone additional genes in much the same way that Class I EPSPS gene probes have been used to clone other Class I genes. An example of the latter was in the cloning of  
10 the *A. thaliana* EPSPS gene using the *P. hybrida* gene as a probe (Klee et al., 1987).

- Glyphosate tolerant EPSPS activity has been reported previously for EPSP synthases from a number of sources. These enzymes have not been characterized to any extent in most cases.  
15 The use of Class I and Class II EPSPS gene probes or antibody probes provide a rapid means of initially screening for the nature of the EPSPS and provide tools for the rapid cloning and characterization of the genes for such enzymes.

- Two of the three genes described were isolated from  
20 bacteria that were isolated from a glyphosate treatment facility (Strains CP4 and LBAA). The third (PG2982) was from a bacterium that had been isolated from a culture collection strain. This latter isolation suggests that exposure to glyphosate may not be a prerequisite for the isolation of high glyphosate tolerant  
25 EPSPS enzymes and that the screening of collections of bacteria could yield additional isolates. It is possible to enrich for glyphosate degrading or glyphosate resistant microbial populations (Quinn et al., 1988; Talbot et al., 1984) in cases where it was felt that enrichment for such microorganisms would enhance  
30 the isolation frequency of Class II EPSPS microorganisms. Additional bacteria containing class II EPSPS gene have also been

identified. A bacterium called C12, isolated from the same treatment column beads as CP4 (see above) but in a medium in which glyphosate was supplied as both the carbon and phosphorus source, was shown by Southern analysis to hybridize with a probe consisting of the CP4 EPSPS coding sequence. This result, in conjunction with that for strain LBAA, suggests that this enrichment method facilitates the identification of Class II EPSPS isolates. New bacterial isolates containing Class II EPSPS genes have also been identified from environments other than glyphosate waste treatment facilities. An inoculum was prepared by extracting soil (from a recently harvested soybean field in Jerseyville, Illinois) and a population of bacteria selected by growth at 28°C in Dworkin-Foster medium containing glyphosate at 10 mM as a source of carbon (and with cycloheximide at 100 µg/ml to prevent the growth of fungi). Upon plating on L-agar media, five colony types were identified. Chromosomal DNA was prepared from 2ml L-broth cultures of these isolates and the presence of a Class II EPSPS gene was probed using a the CP4 EPSPS coding sequence probe by Southern analysis under stringent hybridization and washing conditions. One of the soil isolates, S2, was positive by this screen.

Relationships between different EPSPS genes

The deduced amino acid sequences of a number of Class I and the Class II EPSPS enzymes were compared using the Bestfit computer program provided in the UWGCG package (Devereux et al. 1984). The degree of similarity and identity as determined using this program is reported. The degree of similarity/identity determined within Class I and Class II protein sequences is remarkably high, for instance, comparing *E. coli* with *S. typhimurium* (similarity/identity = 93%/88%) and even

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comparing *E. coli* with a plant EPSPS (*Petunia hybrida*; 72%/55%). This data is shown in Table IV. The comparison of sequences between Class I and Class II, however, shows only a very low degree of relatedness between the Classes (similarity/identity =

- 5 50-53%/23-30%). The display of the Bestfit analysis for the *E. coli* (SEQ ID NO:8) and CP4 (SEQ ID NO:3) sequences shows the positions of the conserved residues and is presented in Figure 6. Previous analyses of EPSPS sequences had noted the high degree of conservation of sequences of the enzymes and the almost 10 invariance of sequences in two regions - the "20-35" and "95-107" regions (Gasser et al., 1988; numbered according to the Petunia EPSPS sequence) - and these regions are less conserved in the case of CP4 and LBAA when compared to Class I bacterial and plant EPSPS sequences (see Figure 6 for a comparison of the *E. coli* and 15 CP4 EPSPS sequences with the *E. coli* sequence appearing as the top sequence in the Figure). The corresponding sequences in the CP4 Class II EPSPS are:

PGDKSISHRSFMFGGL (SEQ ID NO:32) and LDFGNAATGCRLT (SEQ ID NO:33).

20

These comparisons show that the overall relatedness of Class I and Class II EPSPS proteins is low and that sequences in putative conserved regions have also diverged considerably.

- 25 In the CP4 EPSPS an alanine residue is present at the "glycine101" position. The replacement of the conserved glycine (from the "95-107" region) by an alanine results in an elevated  $K_i$  for glyphosate and in an elevation in the  $K_m$  for PEP in Class I EPSPS. In the case of the CP4 EPSPS, which contains an alanine 30 at this position, the  $K_m$  for PEP is in the low range, indicating that the Class II enzymes differ in many aspects from the EPSPS enzymes heretofore characterized.

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Within the Class II isolates, the degree of similarity/identity is as high as that noted for that within Class I (Table IV). Figure 7 displays the Bestfit computer program alignment of the CP4 (SEQ ID NO:3) and LBAA (SEQ ID NO:5)

5 EPSPS deduced amino acid sequences with the CP4 sequence appearing as the top sequence in the Figure. The symbols used in Figures 6 and 7 are the standard symbols used in the Bestfit computer program to designate degrees of similarity and identity.

10 **Table IV Comparison of relatedness of EPSPS protein sequences<sup>1</sup>**

**Comparison between Class I and Class II EPSPS protein sequences**

	<u>similarity</u>	<u>identity</u>
<i>E. coli</i> vs. CP4	52.8	26.3
15 <i>E. coli</i> vs. LBAA	52.1	26.7
<i>S. typhimurium</i> vs. CP4	51.8	25.8
<i>B. pertussis</i> vs. CP4	52.8	27.3
<i>S. cerevisiae</i> vs. CP4	53.5	29.9
<i>P. hybrida</i> vs. CP4	50.2	23.4

20

**Comparison between Class I EPSPS protein sequences**

	<u>similarity</u>	<u>identity</u>
<i>E. coli</i> vs. <i>S. typhimurium</i>	93.0	88.3
<i>P. hybrida</i> vs. <i>E. coli</i>	71.9	54.5

25

**Comparison between Class II EPSPS protein sequences**

	<u>similarity</u>	<u>identity</u>
<i>Agrobacterium</i> sp. strain CP4 vs. <i>Achromobacter</i> sp.		
30 strain LBAA	89.9	83.7

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- 1 The EPSPS sequences compared here were obtained from the  
following references: *E. coli*, Rogers et al., 1983; *S. typhimurium*,  
Stalker et al., 1985; *Petunia hybrida*, Shah et al., 1986; *B. pertussis*,  
5 Maskell et al., 1988; and *S. cerevisiae*, Duncan et al., 1987.

One difference that may be noted between the deduced  
amino acid sequences of the CP4 and LBAA EPSPS proteins is at  
position 100 where an Alanine is found in the case of the CP4  
enzyme and a Glycine is found in the case of the LBAA enzyme.  
10 In the Class I EPSPS enzymes a Glycine is usually found in the  
equivalent position, i.e Glycine96 in *E. coli* and *K. pneumoniae* and  
Glycine101 in Petunia.. In the case of these three enzymes it has  
been reported that converting that Glycine to an Alanine results in  
an elevation of the appKi for glyphosate and a concomitant  
15 elevation in the appKm for PEP (Kishore et al. 1986; Kishore and  
Shah, 1988; Sost and Amrhein, 1990), which, as discussed above,  
makes the enzyme less efficient especially under conditions of  
lower PEP concentrations. The Glycine100 of the LBAA EPSPS  
20 was converted to an Alanine and both the appKm for PEP and the  
appKi for glyphosate were determined for the variant. The  
Glycine100Alanine change was introduced by mutagenesis using  
the following primer:

CGGCAATGCCGCCACCGGGCGCGGCC (SEQ ID NO:34)

25 and both the wild type and variant genes were expressed in *E. coli*  
in a *RecA* promoter expression vector (pMON17201 and  
pMON17264, respectively) and the appKm's and appKi's  
determined in crude lysates. The data indicate that the  
appKi(glyphosate) for the G100A variant is elevated about 16-fold  
30 (Table V). This result is in agreement with the observation of the  
importance of this G-A change in raising the appKi(glyphosate) in

the Class I EPSPS enzymes. However, in contrast to the results in the Class I G-A variants, the appK<sub>m</sub>(PEP) in the Class II (LBAA) G-A variant is unaltered. This provides yet another distinction between the Class II and Class I EPSPS enzymes.

5

Table V

		<u>appK<sub>m</sub>(PEP)</u>	<u>appK<sub>i</sub>( glyphosate)</u>
Lysate prepared from:			
10	<i>E. coli/pMON17201</i> (wild type)	5.3 μM	28 μM*
	<i>E. coli/pMON17264</i> (G100A variant)	5.5 μM	459 μM*

@ range of PEP: 2-40 μM

15 \* range of glyphosate: 0-310 μM; # range of glyphosate: 0-5000 μM.

The LBAA G100A variant, by virtue of its superior kinetic properties, is capable of imparting improved glyphosate *in planta*.

20 Modification and Resynthesis of the *Agrobacterium* sp. strain CP4 EPSPS Gene Sequence

The EPSPS gene from *Agrobacterium* sp. strain CP4 contains sequences that could be inimical to high expression of the gene in plants. These sequences include potential polyadenylation sites that are often A+T rich, a higher G+C% than that frequently found in plant genes (63% *versus* ~50%), concentrated stretches of G and C residues, and codons that are not used frequently in plant genes. The high G+C% in the CP4 EPSPS gene has a number of potential consequences including the following: a higher usage of G or C than that found in plant genes in the third position in codons, and the potential to form strong hair-pin

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structures that may affect expression or stability of the RNA. The reduction in the G+C content of the CP4 EPSPS gene, the disruption of stretches of G's and C's, the elimination of potential polyadenylation sequences, and improvements in the codon usage 5 to that used more frequently in plant genes, could result in higher expression of the CP4 EPSPS gene in plants.

A synthetic CP4 gene was designed to change as completely as possible those inimical sequences discussed above. In summary, the gene sequence was redesigned to eliminate as 10 much as possible the following sequences or sequence features (while avoiding the introduction of unnecessary restriction sites): stretches of G's and C's of 5 or greater; and A+T rich regions (predominantly) that could function as polyadenylation sites or potential RNA destabilization region. The sequence of this gene is 15 shown in Figure 8 (SEQ ID NO:9). This coding sequence was expressed in *E. coli* from the *RecA* promoter and assayed for EPSPS activity and compared with that from the native CP4 EPSPS gene. The apparent *Km* for PEP for the native and synthetic genes was 11.8 and 12.7, respectively, indicating that the enzyme 20 expressed from the synthetic gene was unaltered. The N-terminus of the coding sequence was mutagenized to place an Sphi site at the ATG to permit the construction of the CTP2-CP4 synthetic fusion for chloroplast import. The following primer was 25 used to accomplish this mutagenesis:  
GGACGGCTGCTTGACCGTGAAAGCATGCTTAAGCTTGGCGT  
AATCATGG (SEQ ID NO:35).

Expression of Chloroplast Directed CP4 EPSPS

The glyphosate target in plants, the 30 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS) enzyme, is located in the chloroplast. Many chloroplast-localized proteins,

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including EPSPS, are expressed from nuclear genes as precursors and are targeted to the chloroplast by a chloroplast transit peptide (CTP) that is removed during the import steps. Examples of other such chloroplast proteins include the small subunit (SSU) of 5 Ribulose-1,5-bisphosphate carboxylase (RUBISCO), Ferredoxin, Ferredoxin oxidoreductase, the Light-harvesting-complex protein I and protein II, and Thioredoxin F. It has been demonstrated *in vivo* and *in vitro* that non-chloroplast proteins may be targeted to the chloroplast by use of protein fusions with a CTP and that a CTP 10 sequence is sufficient to target a protein to the chloroplast.

A CTP-CP4 EPSPS fusion was constructed between the *Arabidopsis thaliana* EPSPS CTP (Klee et al., 1987) and the CP4 EPSPS coding sequences. The *Arabidopsis* CTP was engineered by site-directed mutagenesis to place a *Sph*I restriction site at the 15 CTP processing site. This mutagenesis replaced the Glu-Lys at this location with Cys-Met. The sequence of this CTP, designated as CTP2 (SEQ ID NO:10), is shown in Figure 9. The N-terminus of the CP4 EPSPS gene was modified to place a *Sph*I site that spans the Met codon. The second codon was converted to one for leucine 20 in this step also. This change had no apparent effect on the *in vivo* activity of CP4 EPSPS in *E. coli* as judged by rate of complementation of the *aroA* allele. This modified N-terminus was then combined with the *Sac*I C-terminus and cloned downstream of the CTP2 sequences. The CTP2-CP4 EPSPS fusion 25 was cloned into pBlueScript KS(+). This vector may be transcribed *in vitro* using the T7 polymerase and the RNA translated with <sup>35</sup>S-Methionine to provide material that may be evaluated for import into chloroplasts isolated from *Lactuca sativa* using the methods described hereinafter (della-Cioppa et al., 1986, 1987).

30 This template was transcribed *in vitro* using T7 polymerase and the <sup>35</sup>S-methionine-labeled CTP2-CP4 EPSPS material was shown

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to import into chloroplasts with an efficiency comparable to that for the control Petunia EPSPS (control =  $^{35}$ S labeled PreEPSPS [pMON6140; della-Cioppa et al., 1986]).

In another example the *Arabidopsis* EPSPS CTP, 5 designated as CTP3, was fused to the CP4 EPSPS through an EcoRI site. The sequence of this CTP3 (SEQ ID NO:12) is shown in Figure 10. An EcoRI site was introduced into the *Arabidopsis* EPSPS mature region around amino acid 27, replacing the sequence -Arg-Ala-Leu-Leu- with -Arg-Ile-Leu-Leu- in the 10 process. The primer of the following sequence was used to modify the N-terminus of the CP4 EPSPS gene to add an EcoRI site to effect the fusion to the CTP3:

GGAAGACGCCCAGAATTCACGGTGCAAGCAGCCGG

(SEQ ID NO:36) (the EcoRI site is underlined).

15 This CTP3-CP4 EPSPS fusion was also cloned into the pBlueScript vector and the T7 expressed fusion was found to also import into chloroplasts with an efficiency comparable to that for the control Petunia EPSPS (pMON6140).

A related series of CTPs, designated as CTP4 (*SphI*) 20 and CTP5 (*EcoRI*), based on the Petunia EPSPS CTP and gene were also fused to the *SphI*- and *EcoRI*-modified CP4 EPSPS gene sequences. The *SphI* site was added by site-directed mutagenesis to place this restriction site (and change the amino acid sequence to -Cys-Met-) at the chloroplast processing site. All of the CTP-CP4 25 EPSPS fusions were shown to import into chloroplasts with approximately equal efficiency. The CTP4 (SEQ ID NO:14) and CTP5 (SEQ ID NO:16) sequences are shown in Figures 11 and 12.

A CTP2-LBAA EPSPS fusion was also constructed following the modification of the N-terminus of the LBAA EPSPS 30 gene by the addition of a *SphI* site. This fusion was also found to be imported efficiently into chloroplasts.

By similar approaches, the CTP2-CP4 EPSPS and the CTP4-CP4 EPSPS fusion have also been shown to import efficiently into chloroplasts prepared from the leaf sheaths of corn. These results indicate that these CTP-CP4 fusions could also provide 5 useful genes to impart glyphosate tolerance in monocot species.

Those skilled in the art will recognize that various chimeric constructs can be made which utilize the functionality of a particular CTP to import a Class II EPSPS enzyme into the plant cell chloroplast. The chloroplast import of the Class II EPSPS can 10 be determined using the following assay.

#### Chloroplast Uptake Assay

Intact chloroplasts are isolated from lettuce (*Lactuca sativa*, var. *longifolia*) by centrifugation in Percoll/ficoll gradients 15 as modified from Bartlett et al (1982). The final pellet of intact chloroplasts is suspended in 0.5 ml of sterile 330 mM sorbitol-in 50 mM Hepes-KOH, pH 7.7, assayed for chlorophyll (Arnon, 1949), and adjusted to the final chlorophyll concentration of 4 mg/ml (using sorbitol/Hepes). The yield of intact chloroplasts from a 20 single head of lettuce is 3-6mg chlorophyll.

A typical 300 µl uptake experiment contained 5 mM ATP, 8.3 mM unlabeled methionine, 322 mM sorbitol, 58.3 mM Hepes-KOH (pH 8.0), 50 µl reticulocyte lysate translation products, and intact chloroplasts from *L. sativa* (200 µg chlorophyll). The 25 uptake mixture is gently rocked at room temperature (in 10 x 75 mm glass tubes) directly in front of a fiber optic illuminator set at maximum light intensity (150 Watt bulb). Aliquot samples of the uptake mix (about 50 µl) are removed at various times and fractionated over 100 µl silicone-oil gradients (in 150 µl 30 polyethylene tubes) by centrifugation at 11,000 X g for 30 seconds. Under these conditions, the intact chloroplasts form a pellet under

the silicone-oil layer and the incubation medium (containing the reticulocyte lysate) floats on the surface. After centrifugation, the silicone-oil gradients are immediately frozen in dry ice. The chloroplast pellet is then resuspended in 50-100 µl of lysis buffer (10 mM Hepes-KOH pH 7.5, 1 mM PMSF, 1 mM benzamidine, 5 mM e-amino-n-caproic acid, and 30 µg/ml aprotinin) and centrifuged at 15,000 X g for 20 minutes to pellet the thylakoid membranes.

5      The clear supernatant (stromal proteins) from this spin, and an aliquot of the reticulocyte lysate incubation medium from each

10     uptake experiment, are mixed with an equal volume of 2X SDS-PAGE sample buffer for electrophoresis (Laemmli, 1970).

SDS-PAGE is carried out according to Laemmli (1970) in 3-17% (w/v) acrylamide slab-gels (60 mm X 1.5 mm) with 3% (w/v) acrylamide stacking gels (5 mm X 1.5 mm). The gel is fixed 15     for 20-30 min in a solution with 40% methanol and 10% acetic acid. Then, the gel is soaked in EN<sup>3</sup>HANCE™ (DuPont) for 20-30 minutes, followed by drying the gel on a gel dryer. The gel is imaged by autoradiography, using an intensifying screen and an overnight exposure to determine whether the CP4 EPSPS is

20     imported into the isolated chloroplasts.

### PLANT TRANSFORMATION

Plants which can be made glyphosate tolerant by 25     practice of the present invention include, but are not limited to, soybean, cotton, corn, canola, oil seed rape, flax, sugarbeet, sunflower, potato, tobacco, tomato, wheat, rice, alfalfa and lettuce as well as various tree, nut and vine species.

A double-stranded DNA molecule of the present 30     invention ("chimeric gene") can be inserted into the genome of a plant by any suitable method. Suitable plant transformation

vectors include those derived from a Ti plasmid of *Agrobacterium tumefaciens*, as well as those disclosed, e.g., by Herrera-Estrella (1983), Bevan (1984), Klee (1985) and EPO publication 120,516 (Schilperoort et al.). In addition to plant transformation vectors 5 derived from the Ti or root-inducing (Ri) plasmids of *Agrobacterium*, alternative methods can be used to insert the DNA constructs of this invention into plant cells. Such methods may involve, for example, the use of liposomes, electroporation, chemicals that increase free DNA uptake, free DNA delivery via 10 microprojectile bombardment, and transformation using viruses or pollen.

Class II EPSPS Plant transformation vectors

Class II EPSPS DNA sequences may be engineered 15 into vectors capable of transforming plants by using known techniques. The following description is meant to be illustrative and not to be read in a limiting sense. One of ordinary skill in the art would know that other plasmids, vectors, markers, promoters, etc. would be used with suitable results. The CTP2-CP4 EPSPS 20 fusion was cloned as a *Bgl*II-*Eco*RI fragment into the plant vector pMON979 (described below) to form pMON17110, a map of which is presented in Figure 13. In this vector the CP4 gene is expressed from the enhanced CaMV35S promoter (E35S; Kay et al. 1987). A FMV35S promoter construct (pMON17116) was completed in the 25 following way: The *Sal*I-*Not*I and the *Not*I-*Bgl*II fragments from pMON979 containing the Spc/AAC(3)-III/oriV and the pBR322/Right Border/NOS 3'/CP4 EPSPS gene segment from pMON17110 were ligated with the *Xba*I-*Bgl*II FMV35S promoter fragment from pMON981. These vectors were introduced into 30 the plant and canola.

A series of vectors was also completed in the vector pMON977 in which the CP4 EPSPS gene, the CTP2-CP4 EPSPS fusion, and the CTP3-CP4 fusion were cloned as *Bgl*II-*Sac*I fragments to form pMON17124, pMON17119, and pMON17120, 5 respectively. These plasmids were introduced into tobacco. A pMON977 derivative containing the CTP2-LBAÁ EPSPS gene was also completed (pMON17206) and introduced into tobacco.

The pMON979 plant transformation/expression vector was derived from pMON886 (described below) by replacing the 10 neomycin phosphotransferase typeII (KAN) gene in pMON886 with the 0.89 kb fragment containing the bacterial gentamicin-3-N-acetyltransferase type III (AAC(3)-III) gen (Kayford et al., 1988). The chimeric P-35S/AA(3)-III/NOS 3' gene encodes gentamicin resistance which permits selection of 15 transformed plant cells. pMON979 also contains a 0.95 kb expression cassette consisting of the enhanced CaMV 35S promoter (Kay et al., 1987), several unique restriction sites, and the NOS 3' end (P-En-CaMV35S/NOS 3'). The rest of the pMON979 DNA segments are exactly the same as in pMON886.

20 Plasmid pMON886 is made up of the following segments of DNA. The first is a 0.93 kb *Aval* to engineered-*EcoRV* fragment isolated from transposon Tn7 that encodes bacterial spectinomycin/streptomycin resistance (Spc/Str), which is a determinant for selection in *E. coli* and *Agrobacterium tumefaciens*. This is joined to the 1.61 kb segment of DNA 25 encoding a chimeric kanamycin resistance which permits selection of transformed plant cells. The chimeric gene (P-35S/KAN/NOS 3') consists of the cauliflower mosaic virus (CaMV) 35S promoter, the neomycin phosphotransferase typeII (KAN) gene, and the 3'-nontranslated region of the nopaline synthase gene (NOS 3') (Fraley et al., 1983). The next segment is 30

the 0.75 kb *oriV* containing the origin of replication from the RK2 plasmid. It is joined to the 3.1 kb *Sa*I to *Pvu*I segment of pBR322 (*ori*322) which provides the origin of replication for maintenance in *E. coli* and the *bom* site for the conjugational transfer into the 5 *Agrobacterium tumefaciens* cells. The next segment is the 0.36 kb *Pvu*I to *Bcl*I from pTiT37 that carries the nopaline-type T-DNA right border (Fraley et al., 1985).

The pMON977 vector is the same as pMON981 except for the presence of the P-En-CaMV35S promoter in place of the 10 FMV35S promoter (see below).

The pMON981 plasmid contains the following DNA segments: the 0.93 kb fragment isolated from transposon Tn7 encoding bacterial spectinomycin/streptomycin resistance [Spc/Str; a determinant for selection in *E. coli* and *Agrobacterium tumefaciens* (Fling et al., 1985)]; the chimeric kanamycin 15 resistance gene engineered for plant expression to allow selection of the transformed tissue, consisting of the 0.35 kb cauliflower mosaic virus 35S promoter (P-35S) (Odell et al., 1985), the 0.83 kb neomycin phosphotransferase typeII gene (KAN), and the 0.26 kb 20 3'-nontranslated region of the nopaline synthase gene (NOS 3') (Fraley et al., 1983); the 0.75 kb origin of replication from the RK2 plasmid (*oriV*) (Stalker et al., 1981); the 3.1 kb *Sa*I to *Pvu*I segment of pBR322 which provides the origin of replication for maintenance 25 in *E. coli* (*ori*-322) and the *bom* site for the conjugational transfer into the *Agrobacterium tumefaciens* cells, and the 0.36 kb *Pvu*I to *Bcl*I fragment from the pTiT37 plasmid containing the nopaline-type T-DNA right border region (Fraley et al., 1985). The expression cassette consists of the 0.6 kb 35S promoter from the figwort mosaic virus (P-FMV35S) (Gowda et al., 1989) and the 0.7 30 kb 3' non-translated region of the pea *rbcS-E9* gene (E9 3') (Coruzzi et al., 1984 and Morelli et al., 1985). The 0.6 kb *Ssp*I fragment

containing the FMV35S promoter (Figure 1) was engineered to place suitable cloning sites downstream of the transcriptional start site. The CTP2-CP4syn gene fusion was introduced into plant expression vectors (including pMON981, to form pMON17131; 5 Figure 14) and transformed into tobacco, canola, potato, tomato, sugarbeet, cotton, lettuce, cucumber, oil seed rape, poplar, and *Arabidopsis*.

The plant vector containing the Class II EPSPS gene may be mobilized into any suitable *Agrobacterium* strain for 10 transformation of the desired plant species. The plant vector may be mobilized into an ABI *Agrobacterium* strain. A suitable ABI strain is the A208 *Agrobacterium tumefaciens* carrying the disarmed Ti plasmid pTiC58 (pMP90RK) (Koncz and Schell, 1986). The Ti plasmid does not carry the T-DNA phytohormone genes 15 and the strain is therefore unable to cause the crown gall disease. Mating of the plant vector into ABI was done by the triparental conjugation system using the helper plasmid pRK2013 (Ditta et al., 1980). When the plant tissue is incubated with the ABI::plant 20 vector conjugate, the vector is transferred to the plant cells by the *vir* functions encoded by the disarmed pTiC58 plasmid. The vector opens at the T-DNA right border region, and the entire plant vector sequence may be inserted into the host plant chromosome. The pTiC58 Ti plasmid does not transfer to the plant cells but remains in the *Agrobacterium*.

25

#### Class II EPSPS free DNA vectors

Class II EPSPS genes may also be introduced into plants through direct delivery methods. A number of direct delivery vectors were completed for the CP4 EPSPS gene. The 30 vector pMON13640, a map of which is presented in Figure 15, is described here. The plasmid vector is based on a pUC plasmid

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(Vieira and Messing, 1987) containing, in this case, the *nptII* gene (kanamycin resistance; KAN) from Tn903 to provide a selectable marker in *E. coli*. The CTP4-EPSPS gene fusion is expressed from the P-FMV35S promoter and contains the NOS 3' polyadenylation sequence fragment and from a second cassette consisting of the E35S promoter, the CTP4-CP4 gene fusion and the NOS 3' sequences. The scoreable GUS marker gene (Jefferson et al. 1987) is expressed from the mannopine synthase promoter (P-MAS; Velten et al., 1984) and the soybean 7S storage protein gene 5 3' sequences (Schuler et al., 1982). Similar plasmids could also be made in which CTP-CP4 EPSPS fusions are expressed from the enhanced CaMV35S promoter or other plant promoters. Other 10 vectors could be made that are suitable for free DNA delivery into plants and such are within the skill of the art and contemplated to 15 be within the scope of this disclosure.

#### PLANT REGENERATION

When expression of the Class II EPSPS gene is 20 achieved in transformed cells (or protoplasts), the cells (or protoplasts) are regenerated into whole plants. Choice of methodology for the regeneration step is not critical, with suitable protocols being available for hosts from Leguminosae (alfalfa, soybean, clover, etc.), Umbelliferae (carrot, celery, parsnip), 25 Cruciferae (cabbage, radish, rapeseed, etc.), Cucurbitaceae (melons and cucumber), Gramineae (wheat, rice, corn, etc.), Solanaceae (potato, tobacco, tomato, peppers), various floral crops as well as various trees such as poplar or apple, nut crops or vine plants such as grapes. See, e.g., Ammirato, 1984; Shimamoto, 29 1989; F... m 1990; Vasil, 1990.

The following examples are provided to better elucidate the practice of the present invention and should not be interpreted in any way to limit the scope of the present invention. Those skilled in the art will recognize that various modifications, 5 truncations, etc. can be made to the methods and genes described herein while not departing from the spirit and scope of the present invention.

In the examples that follow, EPSPS activity in plants is assayed by the following method. Tissue samples were collected 10 and immediately frozen in liquid nitrogen. One gram of young leaf tissue was frozen in a mortar with liquid nitrogen and ground to a fine powder with a pestle. The powder was then transferred to a second mortar, extraction buffer was added (1 ml /gram), and the sample was ground for an additional 45 seconds. The 15 extraction buffer for Canola consists of 100 mM Tris, 1 mM EDTA, 10 % glycerol, 5 mM DTT, 1 mM BAM, 5 mM ascorbate, 1.0 mg/ml BSA, pH 7.5 (4°C). The extraction buffer for tobacco consists of 100 mM Tris, 10 mM EDTA, 35 mM KCl, 20 % glycerol, 5 mM DTT, 1 mM BAM, 5 mM ascorbate, 1.0 mg/ml BSA, pH 7.5 (4°C). The 20 mixture was transferred to a microfuge tube and centrifuged for 5 minutes. The resulting supernatants were desalting on spin G-50 (Pharmacia) columns, previously equilibrated with extraction buffer (without BSA), in 0.25 ml aliquots. The desalting extracts 25 were assayed for EPSP synthase activity by radioactive HPLC assay. Protein concentrations in samples were determined by the BioRad microprotein assay with BSA as the standard.

Protein concentrations were determined using the BioRad Microprotein method. BSA was used to generate a standard curve ranging from 2 - 24 µg. Either 800 µl of standard

~ dil. test sample was mixed with 200 µl of concentrated BioRad

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Bradford reagent. The samples were vortexed and read at A(595) after ~ 5 minutes and compared to the standard curve.

EPSPS enzyme assays contained HEPES (50 mM), shikimate-3-phosphate (2 mM), NH<sub>4</sub> molybdate (0.1 mM) and KF (5 mM), with or without glyphosate (0.5 or 1.0 mM). The assay mix (30 µl) and plant extract (10 µl) were preincubated for 1 minute at 25°C and the reactions were initiated by adding <sup>14</sup>C-PEP (1 mM). The reactions were quenched after 3 minutes with 50 µl of 90% EtOH/0.1M HOAc, pH 4.5. The samples were spun at 6000 rpm and the resulting supernatants were analyzed for <sup>14</sup>C-EPSP production by HPLC. Percent resistant EPSPS is calculated from the EPSPS activities with and without glyphosate.

The percent conversion of <sup>14</sup>C labeled PEP to <sup>14</sup>C EPSP was determined by HPLC radioassay using a C18 guard column (Brownlee) and an AX100 HPLC column (0.4 X 25 cm, Synchropak) with 0.28 M isocratic potassium phosphate eluant, pH 6.5, at 1 ml/min. Initial velocities were calculated by multiplying fractional turnover per unit time by the initial concentration of the labeled substrate (1 mM). The assay was linear with time up to ~ 3 minutes and 30% turnover to EPSPS. Samples were diluted with 10 mM Tris, 10% glycerol, 10 mM DTT, pH 7.5 (4°C) if necessary to obtain results within the linear range.

In these assays DL-dithiotheitol (DTT), benzamidine (BAM), and bovine serum albumin (BSA, essentially globulin free) were obtained from Sigma. Phosphoenolpyruvate (PEP) was from Boehringer Mannheim and phosphoenol-[1-<sup>14</sup>C]pyruvate (28 Ci/mmol) was from Amersham.

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EXAMPLE 1

Transformed tobacco plants have been generated with a number of the Class II EPSPS gene vectors containing the CP4 EPSPS DNA sequence as described above with suitable expression of the EPSPS. These transformed plants exhibit glyphosate tolerance imparted by the Class II CP4 EPSPS.

Transformation of tobacco employs the tobacco leaf disc transformation protocol which utilizes healthy leaf tissue about 1 month old. After a 15-20 minutes surface sterilization with 10% Clorox plus a surfactant, the leaves are rinsed 3 times in sterile water. Using a sterile paper punch, leaf discs are punched and placed upside down on MS104 media (MS salts 4.3 g/l, sucrose 30 g/l, B5 vitamins 500X 2 ml/l, NAA 0.1 mg/l, and BA 1.0 mg/l) for a 1 day preculture.

The discs are then inoculated with an overnight culture of a disarmed *Agrobacterium* ABI strain containing the subject vector that had been diluted 1/5 (ie: about 0.6 OD). The inoculation is done by placing the discs in centrifuge tubes with the culture. After 30 to 60 seconds, the liquid is drained off and the discs were blotted between sterile filter paper. The discs are then placed upside down on MS104 feeder plates with a filter disc to co-culture.

After 2-3 days of co-culture, the discs are transferred, still upside down, to selection plates with MS104 media. After 2-3 weeks, callus tissue formed, and individual clumps are separated from the leaf discs. Shoots are cleanly cut from the callus when they are large enough to be distinguished from stems. The shoots are placed on hormone-free rooting media (MSO: MS salts 4.3 g/l, sucrose 30 g/l, and B5 vitamins 500X 2 ml/l) with selection for the appropriate antibiotic resistance. Root formation occurred in 1-2

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weeks. Any leaf callus assays are preferably done on rooted shoots while still sterile. Rooted shoots are then placed in soil and kept in a high humidity environment (ie: plastic containers or bags). The shoots are hardened off by gradually exposing them to ambient 5 humidity conditions.

Expression of CP4 EPSPS protein in transformed plants

Tobacco cells were transformed with a number of plant vectors containing the native CP4 EPSPS gene, and using 10 different promoters and/or CTP's. Preliminary evidence for expression of the gene was given by the ability of the leaf tissue from antibiotic selected transformed shoots to recallus on glyphosate. In some cases, glyphosate tolerant callus was selected directly following transformation. The level of expression of the 15 CP4 EPSPS was determined by the level of glyphosate tolerant EPSPS activity (assayed in the presence of 0.5 mM glyphosate) or by Western blot analysis using a goat anti-CP4 EPSPS antibody. The Western blots were quantitated by densitometer tracing and comparison to a standard curve established using purified CP4 20 EPSPS. These data are presented as % soluble leaf protein. The data from a number of transformed plant lines and transformation vectors are presented in Table VI below.

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Table VI Expression of CP4 EPSPS in transformed tobacco tissue

Vector	Plant #	CP4 EPSPS ** (% leaf protein)
5 pMON17110	25313	0.02
pMON17110	25329	0.04
pMON17116	25095	0.02
pMON17119	25106	0.09
pMON17119	25762	0.09
10 pMON17119	25767	0.03

\*\* Glyphosate tolerant EPSPS activity was also demonstrated in leaf extracts for these plants.

15 Glyphosate tolerance has also been demonstrated at the whole plant level in transformed tobacco plants. In tobacco,  $R_o$  transformants of CTP2-CP4 EPSPS were sprayed at 0.4 lb/acre (0.448 kg/hectare), a rate sufficient to kill control non-transformed tobacco plants corresponding to a rating of 3, 1 and 0 at days 7, 14  
20 and 28, respectively, and were analyzed vegetatively and reproductively (Table VII).

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**Table VII Glyphosate tolerance in R<sub>c</sub> tobacco CP4 transformants**

Spray rate = 0.4 lb/acre (0.448kg/hectare)

	<u>Vector/Plant #</u>	<u>Score*</u>			<u>Fertile</u>	
		<u>Vegetative</u>	day 7	day 14	day 28	
5	pMON17110/25313		6	4	2	no
	pMON17110/25329		9	10	10	yes
	pMON17119/25106		9	9	10	yes

- 10 \* Plants are evaluated on a numerical scoring system of 0-10 where a vegetative score of 10 represents no damage relative to nonsprayed controls and 0 represents a dead plant. Reproductive scores (Fertile) are determined at 28 days after spraying and are evaluated as to whether or not the plant is fertile.
- 15

**EXAMPLE 2**

20 Canola plants were transformed with the pMON17110, pMON17116, and pMON17131 vectors and a number of plant lines of the transformed canola were obtained which exhibit glyphosate tolerance.

**25 Plant Material**

Seedlings of *Brassica napus* cv *Westar* were established in 2 inch (~ 5 cm) pots containing Metro Mix 350. They were grown in a growth chamber at 24°C, 16/8 hour photoperiod, light intensity of 400 uEm<sup>-2</sup>sec<sup>-1</sup> (HID lamps). They were fertilized 30 with Peters 20-10-20 General Purpose Special. After 2 1/2 weeks

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they were transplanted to 6 inch (~ 15 cm) pots and grown in a growth chamber at 15/10°C day/night temperature, 16/8 hour photoperiod, light intensity of 800 uEm<sup>-2</sup>sec<sup>-1</sup> (HID lamps). They were fertilized with Peters 15-30-15 Hi-Phos Special.

5

#### Transformation/Selection/Regeneration

Four terminal internodes from plants just prior to bolting or in the process of bolting but before flowering were removed and surfaced sterilized in 70% v/v ethanol for 1 minute, 10 2% w/v sodium hypochlorite for 20 minutes and rinsed 3 times with sterile deionized water. Stems with leaves attached could be refrigerated in moist plastic bags for up to 72 hours prior to sterilization. Six to seven stem segments were cut into 5mm discs with a Redco Vegetable Slicer 200 maintaining orientation of basal 15 end.

The *Agrobacterium* was grown overnight on a rotator at 24°C in 2mls of Luria Broth containing 50mg/l kanamycin, 24mg/l chloramphenicol and 100mg/l spectinomycin. A 1:10 dilution was made in MS (Murashige and Skoog) media giving 20 approximately 9x10<sup>8</sup> cells per ml. This was confirmed with optical density readings at 660 mu. The stem discs (explants) were inoculated with 1.0ml of *Agrobacterium* and the excess was aspirated from the explants.

The explants were placed basal side down in petri 25 plates containing 1/10X standard MS salts, B5 vitamins, 3% sucrose, 0.8% agar, pH 5.7, 1.0mg/l 6-benzyladenine (BA). The plates were layered with 1.5ml of media containing MS salts, B5 vitamins, 3% sucrose, pH 5.7, 4.0mg/l p-chlorophenoxyacetic acid, 0.005mg/l kinetin and covered with sterile filter paper.

30 Following a 2 to 3 day co-culture, the explants were transferred to deep dish petri plates containing MS salts, B5

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vitamins, 3% sucrose, 0.8% agar, pH 5.7, 1mg/l BA, 500mg/l carbenicillin, 50mg/l cefotaxime, 200 mg/l kanamycin or 175mg/l gentamicin for selection. Seven explants were placed on each plate. After 3 weeks they were transferred to fresh media, 5 explants per plate. The explants were cultured in a growth room at 25°C, continuous light (Cool White).

#### Expression Assay

After 3 weeks shoots were excised from the explants.

10 Leaf recallusing assays were initiated to confirm modification of R<sub>o</sub> shoots. Three tiny pieces of leaf tissue were placed on recallusing media containing MS salts, B5 vitamins, 3% sucrose, 0.8% agar, pH 5.7, 5.0mg/l BA, 0.5mg/l naphthalene acetic acid (NAA), 500mg/l carbenicillin, 50mg/l cefotaxime and 200mg/l kanamycin or gentamicin or 0.5mM glyphosate. The leaf assays were incubated in a growth room under the same conditions as explant culture. After 3 weeks the leaf recallusing assays were scored for herbicide tolerance (callus or green leaf tissue) or sensitivity (bleaching).

20

#### Transplantation

At the time of excision, the shoot stems were dipped in Rootone® and placed in 2 inch (~ 5 cm) pots containing Metro-Mix 350 and placed in a closed humid environment. They were placed 25 in a growth chamber at 24°C, 16/8 hour photoperiod, 400 uE m<sup>-1</sup> sec<sup>-2</sup>(HID lamps) for a hardening-off period of approximately 3 weeks.

The seed harvested from R<sub>o</sub> plants is R<sub>1</sub> seed which gives rise to R<sub>1</sub> plants. To evaluate the glyphosate tolerance of an 30 R<sub>o</sub> plant, its progeny are evaluated. Because an R<sub>o</sub> plant is assumed to be hemizygous at each insert location, selfing results

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in maximum genotypic segregation in the R<sub>1</sub>. Because each insert acts as a dominant allele, in the absence of linkage and assuming only one hemizygous insert is required for tolerance expression, one insert would segregate 3:1, two inserts, 15:1, three inserts 63:1, 5 etc. Therefore, relatively few R<sub>1</sub> plants need be grown to find at least one resistant phenotype.

Seed from an R<sub>0</sub> plant is harvested, threshed, and dried before planting in a glyphosate spray test. Various techniques have been used to grow the plants for R<sub>1</sub> spray evaluations. Tests are conducted in both greenhouses and growth chambers. Two planting systems are used; ~ 10 cm pots or plant trays containing 32 or 36 cells. Soil used for planting is either Metro 350 plus three types of slow release fertilizer or plant Metro 350. Irrigation is either overhead in greenhouses or sub-irrigation in growth chambers. Fertilizer is applied as required in irrigation water. Temperature regimes appropriate for canola were maintained. A sixteen hour photoperiod was maintained. At the onset of flowering, plants are transplanted to ~15 cm pots for seed production.

A spray "batch" consists of several sets of R<sub>1</sub> progenies all sprayed on the same date. Some batches may also include evaluations of other than R<sub>1</sub> plants. Each batch also includes sprayed and unsprayed non-transgenic genotypes 25 representing the genotypes in the particular batch which were putatively transformed. Also included in a batch is one or more non-segregating transformed genotypes previously identified as having some resistance.

Two-six plants from each individual R<sub>0</sub> progeny are 30 not sprayed and serve as controls to compare and measure the glyphosate tolerance, as well as to assess any variability not

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induced by the glyphosate. When the other plants reach the 2-4 leaf stage, usually 10 to 20 days after planting, glyphosate is applied at rates varying from 0.28 to 1.12 kg/ha, depending on objectives of the study. Low rate technology using low volumes has been adopted. A laboratory track sprayer has been calibrated to deliver a rate equivalent to field conditions.

A scale of 0 to 10 is used to rate the sprayed plants for vegetative resistance. The scale is relative to the unsprayed plants from the same R<sub>0</sub> plant. A 0 is death, while a 10 represents no visible difference from the unsprayed plant. A higher number between 0 and 10 represents progressively less damage as compared to the unsprayed plant. Plants are scored at 7, 14, and 28 days after treatment (DAT), or until bolting, and a line is given the average score of the sprayed plants within an R<sub>0</sub> plant family.

Six integers are used to qualitatively describe the degree of reproductive damage from glyphosate:

- 0: No floral bud development
- 2: Floral buds present, but aborted prior to opening
- 4: Flowers open, but no anthers, or anthers fail to extrude past petals
- 6: Sterile anthers
- 8: Partially sterile anthers
- 10: Fully fertile flowers

Plants are scored using this scale at or shortly after initiation of flowering, depending on the rate of floral structure development.

#### Expression of EPSPS in Canola

After the 3 week period, the transformed canola plants were assayed for the presence of glyphosate tolerant EPSPS

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activity (assayed in the presence of glyphosate at 0.5mM). The results are shown in Table VIII.

**Table VIII Expression of CP4 EPSPS in transformed Canola plants**

	<u>Vector Control</u>	<u>Plant #</u>	% resistant EPSPS activity of leaf extract (at 0.5 mM glyphosate)
5			0
	pMON17110	41	47
10	pMON17110	52	28
	pMON17110	71	82
	pMON17110	104	75
	pMON17110	172	84
	pMON17110	177	85
15	pMON17110	252	29*
	pMON17110	350	49
	pMON17116	40	25
	pMON17116	99	87
	pMON17116	175	94
20	pMON17116	178	43
	pMON17116	182	18
	pMON17116	252	69
	pMON17116	298	44*
	pMON17116	332	89
25	pMON17116	383	97
	pMON17116	395	52

\*assayed in the presence of 1.0 mM glyphosate

R<sub>1</sub> transformants of canola were then grown in a growth chamber and sprayed with glyphosate at 0.56 kg/ha (kilogram/hectare) and rated vegetatively. These results are shown in Table IXA - IXC. It is to be noted that expression of

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glyphosate resistant EPSPS in all tissues is preferred to observe optimal glyphosate tolerance phenotype in these transgenic plants. In the Tables below, only expression results obtained with leaf tissue are described.

5

**Table IXA Glyphosate tolerance in Class II EPSPS**  
**canola R<sub>1</sub> transformants**

(pMON17110 = P-E35S; pMON17116 = P-FMV35S; R<sub>1</sub> plants;  
 Spray rate = 0.56 kg/ha)

Vector/Plant No.	% resistant	Vegetative	
		EPSPS*	Score**
		day 7	day 14
Control Westar	0	5	3
pMON17110/41	47	6	7
pMON17110/71	82	6	7
pMON17110/177	85	9	10
pMON17116/40	25	9	9
pMON17116/99	87	9	10
pMON17116/175	94	9	10
pMON17116/178	43	6	3
pMON17116/182	18	9	10
pMON17116/383	97	9	10

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Table IXB Glyphosate tolerance in Class II EPSPS  
canola R<sub>1</sub> transformants

(pMON17131 = P-FMV35S; R<sub>1</sub> plants; Spray rate = 0.84 kg/ha)

	Vector/Plant No.	Vegetative score** day 14	Reproductive score day 28	
			day 14	day 28
	17131/78	10	10	
10	17131/102	9	10	
	17131/115	9	10	
	17131/116	9	10	
	17131/157	9	10	
	17131/169	10	10	
15	17131/255	10	10	
	control Westar	1	0	

Table IXC Glyphosate tolerance in Class I EPSPS  
canola transformants

20 (P-E35S; R<sub>2</sub> Plants; Spray rate = 0.28 kg/ha)

	Vector/Plant No.	% resistant EPSPS*	Vegetative		
			Score**		
			day 7	day 14	
	Control Westar	0	4	2	
25	pMON899/715	96	5	6	
	pMON899/744	95	8	8	
	pMON899/794	86	6	4	
	pMON899/818	81	7	8	
	pMON899/885	57	7	6	

- \* % resistant EPSPS activity in the presence of 0.5 mM glyphosate  
 \*\* A vegetative score of 10 indicates no damage, a score of 0 is given to a dead plant.

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The data obtained for the Class II EPSPS transformants may be compared to glyphosate tolerant Class I EPSP transformants in which the same promoter is used to express the EPSPS genes and in which the level of glyphosate tolerant EPSPS activity was comparable for the two types of transformants. A comparison of the data of pMON17110 [in Table IXA] and pMON17131 [Table IXB] with that for pMON899 [in Table IXC; the Class I gene in pMON899 is that from *A. thaliana* (Klee et al., 1987) in which the glycine at position 101 was changed to an alanine] illustrates that the Class II EPSPS is at least as good as that of the Class I EPSPS. An improvement in vegetative tolerance of Class II EPSPS is apparent when one takes into account that the Class II plants were sprayed at twice the rate and were tested as R<sub>1</sub> plants.

#### EXAMPLE 3

Soybean plants were transformed with the pMON13640 (Figure 15) vector and a number of plant lines of the transformed soybean were obtained which exhibit glyphosate tolerance.

Soybean plants are transformed with pMON13640 by the method of microprojectile injection using particle gun technology as described in Christou et al. (1988). The seed harvested from R<sub>0</sub> plants is R<sub>1</sub> seed which gives rise to R<sub>1</sub> plants. To evaluate the glyphosate tolerance of an R<sub>0</sub> plant, its progeny are evaluated. Because an R<sub>0</sub> plant is assumed to be hemizygous at each insert location, selfing results in maximum genotypic segregation in the R<sub>1</sub>. Because each insert acts as a dominant allele, in the absence of linkage and assuming only one hemizygous insert is required for tolerance expression, one insert

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would segregate 3:1, two inserts, 15:1, three inserts 63:1, etc. Therefore, relatively few R<sub>1</sub> plants need be grown to find at least one resistant phenotype.

5       Seed from an R<sub>0</sub> soybean plant is harvested, and dried before planting in a glyphosate spray test. Seeds are planted into 4 inch (~5cm) square pots containing Metro 350. Twenty seedlings from each R<sub>0</sub> plant is considered adequate for testing. Plants are maintained and grown in a greenhouse environment. A 12.5-14 hour photoperiod and temperatures of 30°C day and 24°C night is regulated. Water soluble Peters Pete Lite fertilizer is applied as needed.

10      A spray "batch" consists of several sets of R<sub>1</sub> progenies all sprayed on the same date. Some batches may also include evaluations of other than R<sub>1</sub> plants. Each batch also includes sprayed and unsprayed non-transgenic genotypes representing the genotypes in the particular batch which were putatively transformed. Also included in a batch is one or more non-segregating transformed genotypes previously identified as having some resistance.

15      One to two plants from each individual R<sub>0</sub> progeny are not sprayed and serve as controls to compare and measure the glyphosate tolerance, as well as to assess any variability not induced by the glyphosate. When the other plants reach the first 20 trifoliolate leaf stage, usually 2-3 weeks after planting, glyphosate is applied at a rate equivalent of 128 oz./acre (8.895kg/ha) of Roundup®. A laboratory track sprayer has been calibrated to deliver a rate equivalent to those conditions.

25      A vegetative score of 0 to 10 is used. The score is relative to the unsprayed progenies from the same R<sub>0</sub> plant. A 0 is death, while a 10 represents no visible difference from the

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unsprayed plant. A higher number between 0 and 10 represents progressively less damage as compared to the unsprayed plant. Plants are scored at 7, 14, and 28 days after treatment (DAT). The data from the analysis of one set of transformed and control soybean plants are described on Table X and show that the CP4 EPSPS gene imparts glyphosate tolerance in soybean also.

**Table X    Glyphosate tolerance in Class IEPSPS soybean transformants**

(P-E35S, P-FMV35S; R0 plants; Spray rate = 128 oz./acre)

	<u>Vector/Plant No.</u>	<u>Vegetative score</u>		
		<u>day 7</u>	<u>day 14</u>	<u>day 28</u>
15	13640/40-11	5	6	7
	13640/40-3	9	10	10
	13640/40-7	4	7	7
	control A5403	2	1	0
	controlA5403	1	1	0

#### EXAMPLE 4

The CP4 EPSPS gene may be used to select transformed plant material directly on media containing glyphosate. The ability to select and to identify transformed plant material depends, in most cases, on the use of a dominant selectable marker gene to enable the preferential and continued growth of the transformed tissues in the presence of a normally inhibitory substance. Antibiotic resistance and herbicide tolerance genes have been used almost exclusively as such dominant selectable marker genes in the presence of the corresponding antibiotic or herbicide. The nptII/kanamycin selection scheme is

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probably the most frequently used. It has been demonstrated that CP4 EPSPS is also a useful and perhaps superior selectable marker/selection scheme for producing and identifying transformed plants.

5 A plant transformation vector that may be used in this scheme is pMON17227 (Figure 16). This plasmid resembles many of the other plasmids described infra and is essentially composed of the previously described bacterial replicon system that enables this plasmid to replicate in *E. coli* and to be introduced into and to  
10 replicate in *Agrobacterium*, the bacterial selectable marker gene (Spc/Str), and located between the T-DNA right border and left border is the CTP2-CP4 synthetic gene in the FMV35S promoter-E9  
15 3' cassette. This plasmid also has single sites for a number of restriction enzymes, located within the borders and outside of the expression cassette. This makes it possible to easily add other genes and genetic elements to the vector for introduction into plants.

The protocol for direct selection of transformed plants on glyphosate is outlined for tobacco. Explants are prepared for  
20 pre-culture as in the standard procedure as described in Example 1: surface sterilization of leaves from 1 month old tobacco plants (15 minutes in 10% clorox + surfactant; 3X dH<sub>2</sub>O washes); explants are cut in 0.5 x 0.5 cm squares, removing leaf edges, mid-rib, tip, and petiole end for uniform tissue type; explants are  
25 placed in single layer, upside down, on MS104 plates + 2 ml 4COO5K media to moisten surface; pre-culture 1-2 days. Explants are inoculated using overnight culture of *Agrobacterium* containing the plant transformation plasmid that is adjusted to a titer of 1.2 X 10<sup>9</sup> bacteria/ml with 4COO5K media. Explants are  
30 placed into a centrifuge tube, the *Agrobacterium* suspension is added and the mixture of bacteria and explants is "Vortexed" on

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maximum setting for 25 seconds to ensure even penetration of bacteria. The bacteria are poured off and the explants are blotted between layers of dry sterile filter paper to remove excess bacteria. The blotted explants are placed upside down on MS104 plates + 2ml

- 5 4COO5K media + filter disc. Co-culture is 2-3 days. The explants are transferred to MS104 + Carbenicillin 1000 mg/l + cefotaxime 100 mg/l for 3 days (delayed phase). The explants are then transferred to MS104 + glyphosate 0.05 mM + Carbenicillin 1000 mg/l + cefotaxime 100 mg/l for selection phase. At 4-6 weeks  
10 shoots are cut from callus and placed on MSO + Carbenicillin 500 mg/l rooting media. Roots form in 3-5 days, at which time leaf pieces can be taken from rooted plates to confirm glyphosate tolerance and that the material is transformed.

- The presence of the CP4 EPSPS protein in these  
15 transformed tissues has been confirmed by immunoblot analysis of leaf discs. The data from one experiment with pMON17227 is presented in the following: 139 shoots formed on glyphosate from 400 explants inoculated with *Agrobacterium* ABI/pMON17227; 97 of these were positive on recallusing on glyphosate. These data  
20 indicate a transformation rate of 24 per 100 explants, which makes this a highly efficient and time saving transformation procedure for plants. Similar transformation frequencies have been obtained with pMON17131 and direct selection of transformants on glyphosate with the CP4 EPSPS genes has also been shown in  
25 other plant species, including *Arabidopsis*, potato, tomato, cotton, lettuce, and sugarbeet.

- The pMON17227 plasmid contains single restriction enzyme recognition cleavage sites (NotI, Xhol, and BstXI ) between the CP4 glyphosate selection region and the left border of  
30 the vector for the cloning of additional genes and to facilitate the introduction of these genes into plants.

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EXAMPLE 5

The CP4 EPSPS gene has also been introduced into

- 5 Black Mexican Sweet (BMS) corn cells with expression of the protein and glyphosate resistance detected in callus.

The backbone for this plasmid was a derivative of the high copy plasmid pUC119 (Viera and Messing, 1987). The 1.3Kb FspI-DraI pUC119 fragment containing the origin of replication 10 was fused to the 1.3Kb SmaI-HindIII filled fragment from pKC7 (Rao and Rogers, 1979) which contains the neomycin phosphotransferase type II gene to confer bacterial kanamycin resistance. This plasmid was used to construct a monocot expression cassette vector containing the 0.6kb cauliflower mosaic 15 virus (CaMV) 35S RNA promoter with a duplication of the -90 to -300 region (Kay et al., 1987), an 0.8kb fragment containing an intron from a maize gene in the 5' untranslated leader region, followed by a polylinker and the 3' termination sequences from the nopaline synthase (NOS) gene (Fraley et al., 1983). A 1.7Kb 20 fragment containing the 300bp chloroplast transit peptide from the *Arabidopsis* EPSP synthase fused in frame to the 1.4Kb coding sequence for the bacterial CP4 EPSP synthase was inserted into the monocot expression cassette in the polylinker between the intron and the NOS termination sequence to form the plasmid 25 pMON19653 (Figure 17).

pMON19653 DNA was introduced into *Black Mexican Sweet* (BMS) cells by co-bombardment with EC9, a plasmid containing a sulfonylurea-resistant form of the maize acetolactate synthase gene. 2.5mg of each plasmid was coated onto tungsten 30 particles and introduced into log-phase BMS cells using a PDS-1000 particle gun essentially as described (Klein et al., 1989).

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- Transformants are selected on MS medium containing 20ppb chlorsulfuron. After initial selection on chlorsulfuron, the calli can be assayed directly by Western blot. Glyphosate tolerance can be assessed by transferring the calli to medium containing 5mM 5 glyphosate. As shown in Table XI, CP4 EPSPS confers glyphosate tolerance to corn callus.

**Table XI. Expression of CP4 in BMS Corn Callus - pMON 19653**

	<u>Line</u>	<u>CP4 expression</u> <u>(% extracted protein)</u>
10	284	0.006 %
	287	0.036
	290	0.061
15	295	0.073
	299	0.113
	309	0.042
	313	0.003

- 20 To measure CP4 EPSPS expression in corn callus, the following procedure was used: BMS callus (3 g wet weight) was dried on filter paper (Whatman#1) under vacuum, reweighed, and extraction buffer (500 µl/g dry weight; 100 mM Tris, 1 mM EDTA, 10% glycerol) was added. The tissue was homogenized with a 25 Wheaton overhead stirrer for 30 seconds at 2.8 power setting. After centrifugation (3 minutes, Eppendorf microfuge), the supernatant was removed and the protein was quantitated (BioRad Protein Assay). Samples (50 µg/well) were loaded on an SDS PAGE gel (Jule, 3-17%) along with CP4 EPSPS standard (10 ng). 30 electrophoresed, and transferred to nitrocellulose similarly to a previously described method (Padgette, 1987). The nitrocellulose

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blot was probed with goat anti-CP4 EPSPS IgG, and developed with I-125 Protein G. The radioactive blot was visualized by autoradiography. Results were quantitated by densitometry on an LKB UltraScan XL laser densitometer and are tabulated below in

5 Table X.

Table XII. Glyphosate resistance in BMS Corn Callus  
using pMON 19653

	<u>Vector</u>	<u>Experiment</u>	<u># chlorsulfuron- resistant lines</u>	<u># cross-resistant to Glyphosate</u>
10	19653	253	120	81/ 120 = 67.5 %
	19653	254	80	37/ 80 = 46%
15	EC9 control	253/254	8	0/8 = 0%

Improvements in the expression of Class I EPSPS could also be achieved by expressing the gene using stronger plant promoters, using better 3' polyadenylation signal sequences, 20 optimizing the sequences around the initiation codon for ribosome loading and translation initiation, or by combination of these or other expression or regulatory sequences or factors. It would also be beneficial to transform the desired plant with a Class I EPSPS gene in conjunction with another glyphosate tolerant EPSPS gene 25 or a gene capable of degrading glyphosate in order to enhance the glyphosate tolerance of the transformed plant.

From the foregoing, it will be seen that this invention is one well adapted to attain all the ends and objects hereinabove set forth together with advantages which are obvious and which 30 are inherent to the invention.

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It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of the claims.

5 Since many possible embodiments may be made of the invention without departing from the scope thereof, it is to be understood that all matter herein set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense.

10

#### EXAMPLE 6

15 The LBAA Class II EPSPS gene has been introduced into plants and also imparts glyphosate tolerance. Data on tobacco transformed with pMON17206 (infra) are presented in Table XIII.

Table XIII - Tobacco Glyphosate Sprav Test  
(pMON17206; E35S - CTP2-LBaa EPSPS; 0.4 lbs/ac)

20	Line	7 Day Rating
	33358	9
	34586	9
	33328	9
	34606	9
	33377	9
25	34611	10
	34607	10
	34601	9
	34589	9
	Samsun (Control)	4

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SEQUENCE LISTING

(1) GENERAL INFORMATION:

(1) APPLICANT: Barry, Gerard F.  
Kishore, Ganesh M.  
Padgett, Stephen R.

(II) TITLE OF INVENTION: Glyphosate Tolerant  
5-Enolpyruvylshikimate-3-Phosphate Synthases

(III) NUMBER OF SEQUENCES: 36

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(V) COMPUTER READABLE FORM:

(A) MEDIUM TYPE: Floppy disk  
(B) COMPUTER: IBM PC compatible  
(C) OPERATING SYSTEM: PC-DOS/MS-DOS  
(D) SOFTWARE: PatentIn Release #1.0, Version #1.25

(VI) CURRENT APPLICATION DATA:

(A) APPLICATION NUMBER: US 07/576537  
(B) FILING DATE: 31-AUG-1990  
(C) CLASSIFICATION:

(VIII) ATTORNEY/AGENT INFORMATION:

(A) NAME: Hoerner Jr., Dennis R.  
(B) REGISTRATION NUMBER: 30,914  
(C) REFERENCE/DOCKET NUMBER: 38-21(10535)

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(B) TELEFAX: (314)537-6047

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 597 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: double  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

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## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

TCATCAAAAT ATTTACGAGC ATTCCAGATT GGTTCAATC AACAGGTAC GAGCCATATC	60
ACTTTATTCA AATGGTATC GCCAAAACCA AGAAGGAACCT CCCATCCTCA AAGGTTGTA	120
AGGAAGAAATT CTCAGTCCAA AGCCTCAACA AGGTCAGGGT ACAGAGTCTC CAAACCATA	180
GCCAAAAGCT ACAGGAGATC AATGAAGAAT CTTCAATCAA ACTAAACTAC TGTTCCAGCA	240
CATGCATCAT GGTCAGTAAG TTTCAGAAAA AGACATCCAC CGAAGACTTA AAGTTAGTGG	300
GCATCTTGAA AAGTAATCTT GTCAACATCG ACCAGCTGGC TTGTGGGAC CAGACAAAAA	360
AGGAATGGTG CAGAATTGTT AGGCGCACCT ACCAAAAGCA TCTTGCCTT TATTGCAAAG	420
ATAAAGCAGA TTCCCTAGT ACAAGTGGGG AACAAAATAA CGTGGAAAAG AGCTGTCCCTG	480
ACAGCCCCACT CACTAATGCC TATGACGAAC CCAGTGACGA CCACAAAAGA ATTCCCTCTA	540
TATAAGAAGG CATTGATTCC CATTGAGG ATCATCAGAT ACTAACCAAT ATTTCTC	597

## (2) INFORMATION FOR SEQ ID NO:2:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1982 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: double
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 62..1426

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

AAGCCCGCGT TCTCTCCGGC GCTCCGGCG GAGAGCCGTG GATAGATTAA GGAAGACGCC	60
C ATG TCG CAC CGT GCA AGC AGC CGG CCC GCA ACC GCC CGC AAA TCC	106
Met Ser His Gly Ala Ser Ser Arg Pro Ala Thr Ala Arg Lys Ser	
1 5 10 15	
TCT GGC CTT TCC GGA ACC GTC CGC ATT CCC GGC GAC AAG TCG ATC TCC	154
Ser Gly Leu Ser Gly Thr Val Arg Ile Pro Gly Asp Lys Ser Ile Ser	
20 25 30	
CAC CGG TCC TTC ATG TTC CCC GGT CTC GCG AGC GGT GAA ACG CGC ATC	202
His Arg Ser Phe Met Phe Gly Gly Leu Ala Ser Gly Glu Thr Arg Ile	
35 40 45	

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ACC GGC CTT CTG GAA CCC GAG GAC GTC ATC AAT ACG GGC AAG GCC ATC Thr Gly Leu Leu Glu Gly Glu Asp Val Ile Asn Thr Gly Lys Ala Met	250
50 55 60	
CAG GCC ATG GGC CCC AGC ATC CGT AAG GAA GGC GAC ACC TGG ATC ATC Gln Ala Met Gly Ala Arg Ile Arg Lys Glu Gly Asp Thr Trp Ile Ile	298
65 70 75	
GAT GGC GTC GGC AAT GGC GGC CTC CTG GCG CCT GAG GCG CCG CTC GAT Asp Gly Val Gly Asn Gly Leu Leu Ala Pro Glu Ala Pro Leu Asp	346
80 85 90 95	
TTC GGC AAT GCC CCC AGC GGC TGC CGC CTG ACC ATG GGC CTC GTC GGG Phe Gly Asn Ala Ala Thr Gly Cys Arg Leu Thr Met Gly Leu Val Gly	394
100 105 110	
GTC TAC GAT TTC GAC AGC ACC TTC ATC GGC GAC GCC TCG CTC ACA AAG Val Tyr Asp Phe Asp Ser Thr Phe Ile Gly Asp Ala Ser Leu Thr Lys	442
115 120 125	
CCC CCG ATG GGC CCC GTG TTG AAC CCG CTG CGC GAA ATG GGC GTG CAG Arg Pro Met Gly Arg Val Leu Asn Pro Leu Arg Glu Met Gly Val Gln	490
130 135 140	
GTG AAA TCG GAA GAC GGT GAC CGT CTT CCC GTT ACC TTG CGC GGG CCG Val Lys Ser Glu Asp Gly Asp Arg Leu Pro Val Thr Leu Arg Gly Pro	538
145 150 155	
AAG ACC CCG ACG CCG ATC ACC TAC CGC GTG CCG ATG GCC TCC GCA CAG Lys Thr Pro Thr Pro Ile Thr Tyr Arg Val Pro Met Ala Ser Ala Gln	586
160 165 170 175	
GTG AAG TCC GCC GTG CTC GCC GGC CTC AAC ACG CCC GGC ATC ACG Val Lys Ser Ala Val Leu Leu Ala Gly Leu Asn Thr Pro Gly Ile Thr	634
180 185 190	
ACG GTC ATC GAG CCG ATC ATG ACG CGC GAT CAT ACG GAA AAG ATG CTG Thr Val Ile Glu Pro Ile Met Thr Arg Asp His Thr Glu Lys Met Leu	682
195 200 205	
CAG GGC TTT GGC GCC AAC CTT ACC GTC GAG ACG GAT GCG GAC GGC GTG Gln Gly Phe Gly Ala Asn Leu Thr Val Glu Thr Asp Ala Asp Gly Val	730
210 215 220	
CGC ACC ATC CGC CTG GAA GGC CGC GGC AAG CTC ACC GGC CAA GTC ATC Arg Thr Ile Arg Leu Glu Gly Arg Gly Lys Leu Thr Gly Gln Val Ile	778
225 230 235	
GAC GTG CCG GGC GAC CCG TCC TCG ACG GGC TTC CCG CTG GTT GCG GGC Asp Val Pro Gly Asp Pro Ser Ser Thr Ala Phe Pro Leu Val Ala Ala	826
240 245 250 255	
CTG CTT GTT CCG GGC TCC GAC GTC ACC ATC CTC AAC GTG CTG ATG AAC Leu Leu Val Pro Gly Ser Asp Val Thr Ile Leu Asn Val Leu Met Asn	874
260 265 270	

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CCC ACC CGC ACC GGC CTC ATC CTG ACG CTC CAG CAA ATG GGC GCC GAC Pro Thr Arg Thr Gly Leu Ile Leu Thr Leu Glu Met Gly Ala Asp 275	280	285	922	
ATC GAA GTC ATC AAC CCG CCC CTT CCC GGG GGC GAA GAC GTG GCG GAC Ile Glu Val Ile Asn Pro Arg Leu Ala Gly Glu Asp Val Ala Asp 290	295	300	970	
CTG CGC GTT CGC TCC TCC ACG CTG AAG GGC GTC ACG GTG CCG GAA GAC Leu Arg Val Arg Ser Ser Thr Leu Lys Gly Val Thr Val Pro Glu Asp 305	310	315	1018	
CCC GCG CCT TCG ATG ATC GAC GAA TAT CCG ATT CTC GCT GTC CCC GGC Arg Ala Pro Ser Met Ile Asp Glu Tyr Pro Ile Leu Ala Val Ala Ala 320	325	330	335	1066
CCC TTC GCG GAA GGG GCG ACC GTG ATG AAC GGT CTG GAA GAA CTC CGC Ala Phe Ala Glu Gly Ala Thr Val Met Asn Gly Leu Glu Glu Leu Arg 340	345	350	1114	
GTC AAG GAA AGC GAC CGC CTC TCG GCC GTC GCC AAT GGC CTC AAG CTC Val Lys Glu Ser Asp Arg Leu Ser Ala Val Ala Asn Gly Leu Lys Leu 355	360	365	1162	
AAT GGC GTG GAT TGC GAT GAG GGC GAG ACG TCG CTC GTC GTG CCC GGC Asn Gly Val Asp Cys Asp Glu Gly Glu Thr Ser Leu Val Val Arg Gly 370	375	380	1210	
CGC CCT GAC GGC AAG GGG CTC CGC AAC GGC TCG GGC GCC GGC GTC GGC Arg Pro Asp Gly Lys Gly Leu Gly Asn Ala Ser Gly Ala Ala Val Ala 385	390	395	1258	
ACC CAT CTC GAT CAC CGC ATC GCC ATG AGC TTC CTC GTC ATG GGC CTC Thr His Leu Asp His Arg Ile Ala Met Ser Phe Leu Val Met Gly Leu 400	405	410	415	1306
GTG TCG GAA AAC CCT GTC ACG GTG GAC GAT GGC ACG ATG ATC GCC ACG Val Ser Glu Asn Pro Val Thr Val Asp Asp Ala Thr Met Ile Ala Thr 420	425	430	1354	
AGC TTC CCG GAG TTC ATG GAC CTG ATG GCC GGG CTG GGC GCG AAG ATC Ser Phe Pro Glu Phe Met Asp Leu Met Ala Gly Leu Gly Ala Lys Ile 435	440	445	1402	
GAA CTC TCC GAT ACG AAG GCT GCC TGATGACCTT CACAATGCC ATCGATGGTC Glu Leu Ser Asp Thr Lys Ala Ala 450	455		1456	
CGCGCTGGGC CGGCAAGGGG ACGCTCTCGC GCCCTATCGC GGAGGTCTAT GGCTTCATC ATCTCGATAC GGGCTGACC TATCGGCCA CGGCCAAAGC GCTCGCTGAT CGCGGCGCTGT CGCTTGATGA CGAGGCCGTT GCGGGCGATG TCGCCCCCAA TCTCGATCTT GCGGGCGCTCG ACCGGGTCCGT CTGTCGGCC CATGCCATCG GCGAGGCCGTC TTGAAAGATC GCGGTCAATGC CCTCGGTGCG CGGGGGCGT GTCGAGGCCA AGCGCAGCTT TCGGGCCGCT GAGCCGGCCA			1516	
			1576	
			1636	
			1696	
			1756	

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CCGTGCTGGA TGGACCGGAT ATCCCCACGG TGCTCTGCCCG CGATGCCGCCG CTGAAGCTCT	1816
ATGTCACCGC GTCACCGGAA GTGCCGGCA AACCGCGCTA TGACGAAATC CTGGCAATG	1876
CGGGGTTGGC CGATTACGGG ACGATCCTCG AGCATATCCG CCCCGCGGAC GAGCGGGACA	1936
TGGGTGGGG CGACACTCCT TTGAAGCCCCG CCCACCGATGC GCACTT	1982

## (2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 455 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Met Ser His Gly Ala Ser Ser Arg Pro Ala Thr Ala Arg Lys Ser Ser			
1	5	10	15
Gly Leu Ser Gly Thr Val Arg Ile Pro Gly Asp Lys Ser Ile Ser His			
20	25	30	
Arg Ser Phe Met Phe Gly Gly Leu Ala Ser Gly Glu Thr Arg Ile Thr			
35	40	45	
Gly Leu Leu Glu Gly Glu Asp Val Ile Asn Thr Gly Lys Ala Met Gln			
50	55	60	
Ala Met Gly Ala Arg Ile Arg Lys Glu Gly Asp Thr Trp Ile Ile Asp			
65	70	75	80
Gly Val Gly Asn Gly Gly Leu Leu Ala Pro Glu Ala Pro Leu Asp Phe			
85	90	95	
Gly Asn Ala Ala Thr Gly Cys Arg Leu Thr Met Gly Leu Val Gly Val			
100	105	110	
Tyr Asp Phe Asp Ser Thr Phe Ile Gly Asp Ala Ser Leu Thr Lys Arg			
115	120	125	
Pro Met Gly Arg Val Leu Asn Pro Leu Arg Glu Met Gly Val Gln Val			
130	135	140	
Lys Ser Glu Asp Gly Asp Arg Leu Pro Val Thr Leu Arg Gly Pro Lys			
145	150	155	160
Thr Pro Thr Pro Ile Thr Tyr Arg Val Pro Met Ala Ser Ala Gln Val			
165	170	175	
Lys Ser Ala Val Leu Leu Ala Gly Leu Asn Thr Pro Gly Ile Thr Thr			
180	185	190	

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Val Ile Glu Pro Ile Met Thr Arg Asp His Thr Glu Lys Met Leu Cln  
 195 200 205  
 Gly Phe Gly Ala Asn Leu Thr Val Glu Thr Asp Ala Asp Gly Val Arg  
 210 215 220  
 Thr Ile Arg Leu Glu Gly Arg Gly Lys Leu Thr Gly Cln Val Ile Asp  
 225 230 235 240  
 Val Pro Gly Asp Pro Ser Ser Thr Ala Phe Pro Leu Val Ala Ala Leu  
 245 250 255  
 Leu Val Pro Gly Ser Asp Val Thr Ile Leu Asn Val Leu Met Asn Pro  
 260 265 270  
 Thr Arg Thr Gly Leu Ile Leu Thr Leu Cln Glu Met Gly Ala Asp Ile  
 275 280 285  
 Glu Val Ile Asn Pro Arg Leu Ala Gly Gly Glu Asp Val Ala Asp Leu  
 290 295 300  
 Arg Val Arg Ser Ser Thr Leu Lys Gly Val Thr Val Pro Glu Asp Arg  
 305 310 315 320  
 Ala Pro Ser Met Ile Asp Glu Tyr Pro Ile Leu Ala Val Ala Ala Ala  
 325 330 335  
 Phe Ala Glu Gly Ala Thr Val Met Asn Gly Leu Glu Leu Arg Val  
 340 345 350  
 Lys Glu Ser Asp Arg Leu Ser Ala Val Ala Asn Gly Leu Lys Leu Asn  
 355 360 365  
 Gly Val Asp Cys Asp Glu Gly Glu Thr Ser Leu Val Val Arg Gly Arg  
 370 375 380  
 Pro Asp Gly Lys Gly Leu Gly Asn Ala Ser Gly Ala Ala Val Ala Thr  
 385 390 395 400  
 His Leu Asp His Arg Ile Ala Met Ser Phe Leu Val Met Gly Leu Val  
 405 410 415  
 Ser Glu Asn Pro Val Thr Val Asp Asp Ala Thr Met Ile Ala Thr Ser  
 420 425 430  
 Phe Pro Glu Phe Met Asp Leu Met Ala Gly Leu Gly Ala Lys Ile Glu  
 435 440 445  
 Leu Ser Asp Thr Lys Ala Ala  
 450 455

## (2) INFORMATION FOR SEQ ID NO:4:

- (1) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 1673 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: double

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(D) TOPOLOGY: linear

(II) MOLECULE TYPE: DNA (genomic)

(ix) FEATURE:

(A) NAME/KEY: CDS

(B) LOCATION: 86..1432

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

GTAGCCACAC ATAATTACTA TAGCTAGGAA GCCCCCTATC TCTCAATCCC GCGTGATCGC	60
GCCAAAATGT GACTGTGAAA AATCC ATG TCC CAT TCT GCA TCC CCG AAA CCA Met Ser His Ser Ala Ser Pro Lys Pro	112
1 5	
GCA ACC CCC CGC TCG GAG GCA CTC ACG GGC GAA ATC CGC ATT GCG Ala Thr Ala Arg Arg Ser Glu Ala Leu Thr Gly Glu Ile Arg Ile Pro	160
10 15 20 25	
GCC GAC AAG TCC ATC TCG CAT CGC TCC TTC ATG TTT GGC GGT CTC GCA Gly Asp Lys Ser Ile Ser His Arg Ser Phe Met Phe Gly Gly Leu Ala	208
30 35 40	
TCG GGC GAA ACC CGC ATC ACC CGC CTT CTG GAA GGC GAG GAC GTC ATC Ser Gly Glu Thr Arg Ile Thr Gly Leu Leu Glu Gly Glu Asp Val Ile	256
45 50 55	
AAT ACA CGC CGC GCC ATG CAG GCC ATG GGC GCG AAA ATC CGT AAA GAG Asn Thr Gly Arg Ala Met Gln Ala Met Gly Ala Lys Ile Arg Lys Glu	304
60 65 70	
GCG GAT GTC TCG ATC ATC AAC GGC GTC GGC AAT GGC TGC CTG TTG CAG Gly Asp Val Trp Ile Ile Asn Gly Val Gly Asn Gly Cys Leu Leu Gln	352
75 80 85	
CCC GAA GCT GCG CTC GAT TTC GGC AAT GCC ACC GGC GCG CGC CTC Pro Glu Ala Ala Leu Asp Phe Gly Asn Ala Gly Thr Gly Ala Arg Leu	400
90 95 100 105	
ACC ATG GGC CTT GTC GGC ACC TAT GAC ATG AAG ACC TCC TTT ATC GGC Thr Met Gly Leu Val Gly Thr Tyr Asp Met Lys Thr Ser Phe Ile Gly	448
110 115 120	
GAC GCC TCG CTG TCG AAG CGC CCG ATG GGC CGC GTG CTG AAC CCG TTG Asp Ala Ser Leu Ser Lys Arg Pr Met Gly Arg Val Leu Asn Pro Leu	496
125 130 135	
CGC GAA ATG GGC GTT CAG GTG GAA GCA GGC GAT GGC GAC CGC ATG CCG Arg Glu Met Gly Val Gln Val Glu Ala Ala Asp Gly Asp Arg Met Pro	544
140 145 150	

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CTG ACG CTG ATC GGC CCG AAG ACG CCC AAT CCG ATC ACC TAT CCC GTG Leu Thr Leu Ile Gly Pro Lys Thr Ala Asn Pro Ile Thr Tyr Arg Val 155 160 165	592
CCG ATG GCC TCC GCG CAG GTC AAA TCC CCC GTG CTG CTC GCC GGT CTC Pro Met Ala Ser Ala Gln Val Lys Ser Ala Val Leu Ala Gly Leu 170 175 180 185	640
AAC ACG CCG GGC GTC ACC ACC GTC ATC GAG CCG GTC ATG ACC CCC GAC Asn Thr Pro Gly Val Thr Val Ile Glu Pro Val Met Thr Arg Asp 190 195 200	688
CAC ACC GAA AAC ATG CTG CAG GGC TTT CCC GCC GAC CTC ACG GTC GAG His Thr Glu Lys Met Leu Gln Gly Phe Gly Ala Asp Leu Thr Val Glu 205 210 215	736
ACC GAC AAC GAT GGC GTG CGC CAT ATC CGC ATC ACC CCC CAG GGC AAC Thr Asp Lys Asp Gly Val Arg His Ile Arg Ile Thr Gly Gln Gly Lys 220 225 230	784
CTT GTC CGC CAG ACC ATC GAC GTG CCG GGC GAT CCG TCA TCG ACC GCC Leu Val Gly Gln Thr Ile Asp Val Pro Gly Asp Pro Ser Ser Thr Ala 235 240 245	832
TTC CCG CTC GTT GCC GCC CTT CTG GTG GAA GGT TCC GAC GTC ACC ATC Phe Pro Leu Val Ala Ala Leu Leu Val Glu Gly Ser Asp Val Thr Ile 250 255 260 265	880
CGC AAC GTG CTG ATG AAC CCG ACC CGT ACC CCC CTC ATC CTC ACC TTG Arg Asn Val Leu Met Asn Pro Thr Arg Thr Gly Leu Ile Leu Thr Leu 270 275 280	928
CAG GAA ATG GGC GCC GAT ATC GAA GTG CTC AAT GCC CGT CTT GCA GGC Gln Glu Met Gly Ala Asp Ile Glu Val Leu Asn Ala Arg Leu Ala Gly 285 290 295	976
GCG GAA GAC GTC GCC GAT CTG CGC GTC AGG GCT TCG AAG CTC AAG GGC Gly Glu Asp Val Ala Asp Leu Arg Val Arg Ala Ser Lys Leu Lys Gly 300 305 310	1024
GTC GTC GTT CCG CCG GAA CGT GCG CCG TCG ATG ATC GAC GAA TAT CCC Val Val Val Pro Pro Glu Arg Ala Pro Ser Met Ile Asp Glu Tyr Pro 315 320 325	1072
GTC CTG CGG ATT GCC GCC TCC TTC GCG GAA GGC GAA ACC GTG ATG GAC Val Leu Ala Ile Ala Ala Ser Phe Ala Glu Gly Glu Thr Val Met Asp 330 335 340 345	1120
GGG CTC GAC GAA CTG CGC GTC AAG GAA TCG GAT CGT CTG GCA GCG GTC Gly Leu Asp Glu Leu Arg Val Lys Glu Ser Asp Arg Leu Ala Ala Val 350 355 360	1168
GCA CGC GGC CTT GAA GCC AAC CCC GTC GAT TGC ACC GAA GGC GAG ATG Ala Arg Gly Leu Glu Ala Asn Gly Val Asp Cys Thr Glu Gly Glu Met 365 370 375	1216

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TCG CTG ACG CTT CGC CGC CGC CCC GAC GGC AAG CGA CTG GGC GGC GGC 1264  
 Ser Leu Thr Val Arg Gly Arg Pro Asp Gly Lys Gly Leu Gly Gly Gly  
 380 385 390  
 ACG GTT GCA ACC CAT CTC GAT CAT CGT ATC GCG ATG AGC TTC CTC GTG 1312  
 Thr Val Ala Thr His Leu Asp His Arg Ile Ala Met Ser Phe Leu Val  
 395 400 405  
 ATG GGC CTT CGC CGC GAA AAG CGG GTG ACG GTT GAC GAC AGT AAC ATG 1360  
 Met Gly Leu Ala Ala Glu Lys Pro Val Thr Val Asp Asp Ser Asn Met  
 410 415 420 425  
 ATC GCC ACG TCC TTC CCC GAA TTC ATG GAC ATG ATG CCG GGA TTG GGC 1408  
 Ile Ala Thr Ser Phe Pro Glu Phe Met Asp Met Met Pro Gly Leu Gly  
 430 435 440  
 GCA AAC ATC GAG TTG ACC ATA CTC TAGTCACTCG ACAGCGAAAAA TATTATTTGC 1462  
 Ala Lys Ile Glu Leu Ser Ile Leu  
 445  
 GAGATTGGGC ATTATTACCG GTTGGTCTCA GCGGGGGTTT AATGTCCAAT CTTCCATAACG 1522  
 TAACAGCATC AGGAAATATC AAAAAAGCTT TAGAAGGAAT TGCTAGAGCA GCGACGCCGC 1582  
 CTAAGCTTTC TCAAGACTTC GTTAAAATG TACTGAAATC CGGGGGGGTC CGGGGATCAA 1642  
 ATGACTTCAT TTCTGAGAAA TTGGCCTCGC A 1673

## (2) INFORMATION FOR SEQ ID NO:5:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 449 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

Met Ser His Ser Ala Ser Pro Lys Pro Ala Thr Ala Arg Arg Ser Glu  
 1 5 10 15  
 Ala Leu Thr Gly Glu Ile Arg Ile Pro Gly Asp Lys Ser Ile Ser His  
 20 25 30  
 Arg Ser Phe Met Phe Gly Gly Leu Ala Ser Gly Glu Thr Arg Ile Thr  
 35 40 45  
 Gly Leu Leu Glu Gly Glu Asp Val Ile Asn Thr Gly Arg Ala Met Cln  
 50 55 60  
 Ala Met Gly Ala Lys Ile Arg Lys Glu Gly Asp Val Trp Ile Ile Asn  
 65 70 75 80  
 Gly Val Gly Asn Gly Cys Leu Leu Gln Pro Glu Ala Ala Leu Asp Phe  
 85 90 95

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Gly Asn Ala Gly Thr Gly Ala Arg Leu Thr Met Gly Leu Val Gly Thr  
 100 105 110

Tyr Asp Met Lys Thr Ser Phe Ile Gly Asp Ala Ser Leu Ser Lys Arg  
 115 120 125

Pro Met Gly Arg Val Leu Asn Pro Leu Arg Glu Met Gly Val Gln Val  
 130 135 140

Glu Ala Ala Asp Gly Asp Arg Met Pro Leu Thr Leu Ile Gly Pro Lys  
 145 150 155 160

Thr Ala Asn Pro Ile Thr Tyr Arg Val Pro Met Ala Ser Ala Gln Val  
 165 170 175

Lys Ser Ala Val Leu Leu Ala Gly Leu Asn Thr Pro Gly Val Thr Thr  
 180 185 190

Val Ile Glu Pro Val Met Thr Arg Asp His Thr Glu Lys Met Leu Gln  
 195 200 205

Gly Phe Gly Ala Asp Leu Thr Val Glu Thr Asp Lys Asp Gly Val Arg  
 210 215 220

His Ile Arg Ile Thr Gly Gln Lys Leu Val Gly Gln Thr Ile Asp  
 225 230 235 240

Val Pro Gly Asp Pro Ser Ser Thr Ala Phe Pro Leu Val Ala Ala Leu  
 245 250 255

Leu Val Glu Gly Ser Asp Val Thr Ile Arg Asn Val Leu Met Asn Pro  
 260 265 270

Thr Arg Thr Gly Leu Ile Leu Thr Leu Gln Glu Met Gly Ala Asp Ile  
 275 280 285

Glu Val Leu Asn Ala Arg Leu Ala Gly Gly Glu Asp Val Ala Asp Leu  
 290 295 300

Arg Val Arg Ala Ser Lys Leu Lys Gly Val Val Val Pro Pro Glu Arg  
 305 310 315 320

Ala Pro Ser Met Ile Asp Glu Tyr Pro Val Leu Ala Ile Ala Ala Ser  
 325 330 335

Phe Ala Glu Gly Glu Thr Val Met Asp Gly Leu Asp Glu Leu Arg Val  
 340 345 350

Lys Glu Ser Asp Arg Leu Ala Ala Val Ala Arg Gly Leu Glu Ala Asn  
 355 360 365

Gly Val Asp Cys Thr Glu Gly Glu Met Ser Leu Thr Val Arg Gly Arg  
 370 375 380

Pro Asp Gly Lys Gly Leu Gly Gly Thr Val Ala Thr His Leu Asp  
 385 390 395 400

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His	Arg	Ile	Ala	Met	Ser	Phe	Leu	Val	Met	Gly	Leu	Ala	Ala	Glu	Lys
									410					415	
405															
Pro	Val	Thr	Val	Asp	Asp	Ser	Asn	Met	Ile	Ala	Thr	Ser	Phe	Pro	Glu
														430	
									425						
phe	Met	Asp	Met	Met	Pro	Gly	Leu	Gly	Ala	Lys	Ile	Glu	Leu	Ser	Ile
435							440						445		

Leu

(2) INFORMATION FOR SEQ ID NO:6:

#### 1. SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1500 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: double  
(D) TOPOLOGY: linear

(1) MOLECULE TYPE: DNA (genomic)

(3\*) FEATURE:

- (A) NAME/KEY: CDS  
(B) LOCATION: 34..1380

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

GTGATCGCGC CAAAATGTGA CTGTGAAAAA TCC ATG TCC CAT TCT GCA TCC CCC  
Met Ser His Ser Ala Ser Pro

54

AAA CCA GCA ACC GCC CGC CGG TCG GAG GCA CTC ACG GGC GAA ATC CGC  
 Lys Pro Ala Thr Ala Arg Arg Ser Glu Ala Leu Thr Gly Glu Ile Arg  
 10 15 20

102

10  
ATT CCG GGC GAC AAG TCC ATC TCG CAT CGC TCC TTC ATG TTT GGC GGT  
Ile Pro Gly Asp Lys Ser Ile Ser His Arg Ser Met Phe Gly Gly  
25 30 35

150

CTC GCA TCG GGC GAA ACC CGC ATC ACC GGC CTT CTG GAA GGC GAG GAC  
 Leu Ala Ser Gly Glu Thr Arg Ile Thr Gly Leu Leu Glu Gly Glu Asp  
 40 45 50 55

198

40 GTC ATC AAT ACA GGC CGC CCC ATG CAG GCC ATG CCC GCG AAA ATC CGT  
 Val Ile Asn Thr Gly Arg Ala Met Gln Ala Met Gly Ala Lys Ile Arg  
 60 65 70

246

AAA GAG GGC GAT GTC TGG ATC ATC AAC GGC GTC CGC AAT GGC TGC CTG  
 Lys Glu Gly Asp Val Trp Ile Ile Asn Gly Val Gly Asn Gly Cys Leu  
 75 80 85

294

75 TTG CAG CCC GAA GCT GCG CTC GAT TTC CGC AAT GCC GGA ACC CCC GCG  
Leu Gln Pro Glu Ala Ala Leu Asp Phe Gly Asn Ala Gly Thr Gly Ala  
90 95 100

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CCG CTC ACC ATG CCC CTT GTC GGC ACC TAT GAC ATG AAG ACC TCC TTT Arg Leu Thr Met Gly Leu Val Gly Thr Tyr Asp Met Lys Thr Ser Phe 105 110 115	390
ATC CGC GAC GCC TCG CTG TCG AAG CCG CCG ATG GGC CCC GTG CTC AAC Ile Gly Asp Ala Ser Leu Ser Lys Arg Pro Met Gly Arg Val Leu Asn 120 125 130 135	438
CCG TTG CGC GAA ATG GGC GTT CAG GTG GAA CCA GCC GAT CCC GAC CCC Pro Leu Arg Glu Met Gly Val Gln Val Glu Ala Ala Asp Gly Asp Arg 140 145 150	486
ATG CCG CTG ACG CTG ATC GGC CCG AAG ACC CCC AAT CCG ATC ACC TAT Met Pro Leu Thr Leu Ile Gly Pro Lys Thr Ala Asn Pro Ile Thr Tyr 155 160 165	534
CCC GTG CCG ATG GCC TCC GCG CAG GTA AAA TCC GCC GTG CTG CTC GCC Arg Val Pro Met Ala Ser Ala Gln Val Lys Ser Ala Val Leu Leu Ala 170 175 180	582
GGT CTC AAC ACG CCG CCC GTC ACC ACC GTC ATC CAG CCG GTC ATG ACC Gly Leu Asn Thr Pro Gly Val Thr Val Ile Glu Pro Val Met Thr 185 190 195	630
CCC GAC CAC ACC GAA AAG ATG CTG CAG GGC TTT GGC GCC GAC CTC ACG Arg Asp His Thr Glu Lys Met Leu Gln Gly Phe Gly Ala Asp Leu Thr 200 205 210 215	678
GTC GAG ACC GAC AAG GAT GGC GTG CGC CAT ATC CGC ATC ACC CGC CAG Val Glu Thr Asp Lys Asp Gly Val Arg His Ile Arg Ile Thr Gly Gln 220 225 230	726
GGC AAG CTT GTC GGC CAG ACC ATC GAC GTG CCG GGC GAT CCG TCA TCG Gly Lys Leu Val Gly Gln Thr Ile Asp Val Pro Gly Asp Pro Ser Ser 235 240 245	774
ACC GCC TTC CCG CTC GTT GCC CTT CTG GTG GAA CGT TCC GAC GTC Thr Ala Phe Pro Leu Val Ala Ala Leu Leu Val Glu Gly Ser Asp Val 250 255 260	822
ACC ATC CGC AAC GTG CTG ATG AAC CCG ACC CGT ACC GCC CTC ATC CTC Thr Ile Arg Asn Val Leu Met Asn Pro Thr Arg Thr Gly Leu Ile Leu 265 270 275	870
ACC TTG CAG GAA ATG GGC GCC GAT ATC GAA GTG CTC AAT GCC CGT CTT Thr Leu Gln Glu Met Gly Ala Asp Ile Glu Val Leu Asn Ala Arg Leu 280 285 290 295	918
GCA GGC GGC GAA GAC GTC GCC GAT CTG CGC GTC AGG GCT TCG AAG CTC Ala Gly Gly Glu Asp Val Ala Asp Leu Arg Val Arg Ala Ser Lys Leu 300 305 310	966
AAG GGC CTC GTC GTT CCG CCG GAA CGT CGC CCG TCG ATG ATC GAC GAA Lys Gly Val Val Val Pro Pro Glu Arg Ala Pro Ser Met Ile Asp Glu 315 320 325	1014

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TAT CCG GTC CTG CGC ATT CCC CCC TCC TTC CGC GAA GAA ACC GTG Tyr Pro Val Leu Ala Ile Ala Ala Ser Phe Ala Glu Gly Glu Thr Val 330 335 340	1062
ATG GAC GGG CTC GAC GAA CTG CGC GTC AAG GAA TCG GAT CGT CTG GCA Met Asp Gly Leu Asp Glu Leu Arg Val Lys Glu Ser Asp Arg Leu Ala 345 350 355	1110
GGC GTC GCA CGC GGC CTT GAA GCC AAC GGC GTC GAT TGC ACC GAA GGC Ala Val Ala Arg Gly Leu Glu Ala Asn Gly Val Asp Cys Thr Glu Gly 360 365 370 375	1158
GAG ATG TCG CTG ACG GTT CGC GGC CCC GAC GGC AAG GGA CTG CCC Glu Met Ser Leu Thr Val Arg Gly Arg Pro Asp Gly Lys Gly Leu Gly 380 385 390	1206
GGC CGC ACG GTT GCA ACC CAT CTC GAT CAT CGT ATC GCG ATG AGC TTC Gly Gly Thr Val Ala Thr His Leu Asp His Arg Ile Ala Met Ser Phe 395 400 405	1254
CTC GTG ATG GGC CTT GCG GCG GAA AAG CCG GTG ACG CTT GAC GAC AGT Leu Val Met Gly Leu Ala Ala Glu Lys Pro Val Thr Val Asp Asp Ser 410 415 420	1302
AAC ATG ATC GCC ACG TCC TTC CCC GAA TTC ATG GAC ATG ATG CCG GGA Asn Met Ile Ala Thr Ser Phe Pro Glu Phe Met Asp Met Met Pro Gly 425 430 435	1350
TTG GGC GCA AAG ATC GAG TTG ACC ATA CTC TAGTCACTCG ACAGCGAAAAA Leu Gly Ala Lys Ile Glu Leu Ser Ile Leu 440 445	1400
TATTATTCG GAGATTGGGC ATTATTACCG GTTGGTCTCA GCGGGGGTTT AATGTCCAAT	1460
CTTCCATACG TAACAGCATC AGGAAATATC AAAAAAGCTT	1500

## (2) INFORMATION FOR SEQ ID NO:7:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 449 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

Met Ser His Ser Ala Ser Pro Lys Pro Ala Thr Ala Arg Arg Ser Glu 1 5 10 15
Ala Leu Thr Gly Glu Ile Arg Ile Pro Gly Asp Lys Ser Ile Ser His 20 25 30
Arg Ser Phe Met Phe Gly Gly Leu Ala Ser Gly Glu Thr Arg Ile Thr 35 40 45

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Gly Leu Leu Glu Gly Glu Asp Val Ile Asn Thr Gly Arg Ala Met Gln  
 50 55 60

Ala Met Gly Ala Lys Ile Arg Lys Glu Gly Asp Val Trp Ile Ile Asn  
 65 70 75 80

Gly Val Gly Asn Gly Cys Leu Leu Gln Pro Glu Ala Ala Leu Asp Phe  
 85 90 95

Gly Asn Ala Gly Thr Gly Ala Arg Leu Thr Met Gly Leu Val Gly Thr  
 100 105 110

Tyr Asp Met Lys Thr Ser Phe Ile Gly Asp Ala Ser Leu Ser Lys Arg  
 115 120 125

Pro Met Gly Arg Val Leu Asn Pro Leu Arg Glu Met Gly Val Gln Val  
 130 135 140

Glu Ala Ala Asp Gly Asp Arg Met Pro Leu Thr Leu Ile Gly Pro Lys  
 145 150 155 160

Thr Ala Asn Pro Ile Thr Tyr Arg Val Pro Met Ala Ser Ala Gln Val  
 165 170 175

Lys Ser Ala Val Leu Leu Ala Gly Leu Asn Thr Pro Gly Val Thr Thr  
 180 185 190

Val Ile Glu Pro Val Met Thr Arg Asp His Thr Glu Lys Met Leu Gln  
 195 200 205

Gly Phe Gly Ala Asp Leu Thr Val Glu Thr Asp Lys Asp Gly Val Arg  
 210 215 220

His Ile Arg Ile Thr Gly Gln Gly Lys Leu Val Gly Gln Thr Ile Asp  
 225 230 235 240

Val Pro Gly Asp Pro Ser Ser Thr Ala Phe Pro Leu Val Ala Ala Leu  
 245 250 255

Leu Val Glu Gly Ser Asp Val Thr Ile Arg Asn Val Leu Met Asn Pro  
 260 265 270

Thr Arg Thr Gly Leu Ile Leu Thr Leu Gln Glu Met Gly Ala Asp Ile  
 275 280 285

Glu Val Leu Asn Ala Arg Leu Ala Gly Glu Asp Val Ala Asp Leu  
 290 295 300

Arg Val Arg Ala Ser Lys Leu Lys Gly Val Val Val Pro Pro Glu Arg  
 305 310 315 320

Ala Pro Ser Met Ile Asp Glu Tyr Pro Val Leu Ala Ile Ala Ser  
 325 330 335

Phe Ala Glu Gly Glu Thr Val Met Asp Gly Leu Asp Glu Leu Arg Val  
 340 345 350

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Lys Glu Ser Asp Arg Leu Ala Ala Val Ala Arg Gly Leu Glu Ala Asn  
 355 360 365

Gly Val Asp Cys Thr Glu Gly Glu Met Ser Leu Thr Val Arg Gly Arg  
 370 375 380

Pro Asp Gly Lys Gly Leu Gly Gly Thr Val Ala Thr His Leu Asp  
 385 390 395 400

His Arg Ile Ala Met Ser Phe Leu Val Met Gly Leu Ala Ala Glu Lys  
 405 410 415

Pro Val Thr Val Asp Asp Ser Asn Met Ile Ala Thr Ser Phe Pro Glu  
 420 425 430

Phe Met Asp Met Met Pro Gly Leu Gly Ala Lys Ile Glu Leu Ser Ile  
 435 440 445

Leu

## (2) INFORMATION FOR SEQ ID NO:8:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 423 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:8:

Ser Leu Thr Leu Gln Pro Ile Ala Arg Val Asp Gly Thr Ile Asn Leu  
 1 5 10 15

Pro Gly Ser Lys Thr Val Ser Asn Arg Ala Leu Leu Leu Ala Ala Leu  
 20 25 30

Ala His Gly Lys Thr Val Leu Thr Asn Leu Leu Asp Ser Asp Asp Val  
 35 40 45

Arg His Met Leu Asn Ala Leu Thr Ala Leu Gly Val Ser Tyr Thr Leu  
 50 55 60

Ser Ala Asp Arg Thr Arg Cys Glu Ile Ile Gly Asn Gly Gly Pro Leu  
 65 70 75 80

His Ala Glu Gly Ala Leu Glu Leu Phe Leu Gly Asn Ala Gly Thr Ala  
 85 90 95

Met Arg Pro Leu Ala Ala Leu Cys Leu Gly Ser Asn Asp Ile Val  
 100 105 110

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Leu Thr Gly Glu Pro Arg Met Lys Glu Arg Pro Ile Gly His Leu Val  
 115 120 125  
 Asp Ala Leu Arg Leu Gly Gly Ala Lys Ile Thr Tyr Leu Glu Gln Glu  
 130 135 140  
 Asn Tyr Pro Pro Leu Arg Leu Gln Gly Gly Phe Thr Gly Gly Asn Val  
 145 150 155 160  
 Asp Val Asp Gly Ser Val Ser Ser Gln Phe Leu Thr Ala Leu Leu Met  
 165 170 175  
 Thr Ala Pro Leu Ala Pro Glu Asp Thr Val Ile Arg Ile Lys Gly Asp  
 180 185 190  
 Leu Val Ser Lys Pro Tyr Ile Asp Ile Thr Leu Asn Leu Met Lys Thr  
 195 200 205  
 Phe Gly Val Glu Ile Glu Asn Gln His Tyr Gln Gln Phe Val Val Lys  
 210 215 220  
 Gly Gly Gln Ser Tyr Gln Ser Pro Gly Thr Tyr Leu Val Glu Gly Asp  
 225 230 235 240  
 Ala Ser Ser Ala Ser Tyr Phe Leu Ala Ala Ala Ala Ile Lys Gly Gly  
 245 250 255  
 Thr Val Lys Val Thr Gly Ile Gly Arg Asn Ser Met Gln Gly Asp Ile  
 260 265 270  
 Arg Phe Ala Asp Val Leu Glu Lys Met Gly Ala Thr Ile Cys Trp Gly  
 275 280 285  
 Asp Asp Tyr Ile Ser Cys Thr Arg Gly Glu Leu Asn Ala Ile Asp Met  
 290 295 300  
 Asp Met Asn His Ile Pro Asp Ala Ala Met Thr Ile Ala Thr Ala Ala  
 305 310 315 320  
 Leu Phe Ala Lys Gly Thr Thr Arg Leu Arg Asn Ile Tyr Asn Trp Arg  
 325 330 335  
 Val Lys Glu Thr Asp Arg Leu Phe Ala Met Ala Thr Glu Leu Arg Lys  
 340 345 350  
 Val Gly Ala Glu Val Glu Glu Gly His Asp Tyr Ile Arg Ile Thr Pro  
 355 360 365  
 Pro Glu Lys Leu Asn Phe Ala Glu Ile Ala Thr Tyr Asn Asp His Arg  
 370 375 380  
 Met Ala Met Cys Phe S r Leu Val Ala Leu Ser Asp Thr Pro Val Thr  
 385 390 395 400  
 Ile Leu Asp Pro Lys Cys Thr Ala Lys Thr Phe Pro Asp Tyr Phe Glu  
 405 410 415

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Gln Leu Ala Arg Ile Ser Gln  
420

## (2) INFORMATION FOR SEQ ID NO:9:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 1377 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: double
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:9:

CCATGGCTCA CGGTGCAAGC AGCCGTCAG CAACTGCTCG TAAAGTCCCTCT GGTCTTTCTG	60
CAACCGTCCG TATTCCAGGT GACAAGTCTA TCTCCCACAG GTCCCTCATG TTTGGAGCTC	120
TCGCTAGCGG TGAAAACTCGT ATCACCGGTC TTTTGAAGG TGAAGATGTT ATCAACACTG	180
GTAAGGCTAT GCAAGCTATG CGTGCCAGAA TCCGTAAGGA AGGTGATACT TGGATCATTG	240
ATCGTGTGG TAACGGTCCA CTCCCTGCTC CTGAGGCTCC TCTCGATTTG CGTAACGCTG	300
CAACTGGTTG CCGTTTGACT ATGGGTCTTG TTGGTGTAA CGATTTCGAT AGCAGTTCA	360
TTGGTGACGC TTCTCTCACT AACCGTCCAA TGGGTCGTGT GTTGAACCCA CTTCCGCGAA	420
TGGGTGTGCA GGTGAAGTCT GAACACGGTG ATCGTCTTCC AGTTACCTTG CGTGGACCAA	480
AGACTCCAAC CCCAATCACC TACAGGGTAC CTATGGCTTC CGCTCAAGTG AAGTCCGCTG	540
TTCTGCTTGC TGGTCTCAAC ACCCCAGGT A TCACCACTGT TATCGAGCCA ATCATGACTC	600
GTGACCACAC TGAAAAGATG CTTCAAGGTT TTGGTGTAA CCTTACCGTT GAGACTGATG	660
CTGACCGTGT CGGTACCATC CGTCTTGAAG GTCTGGTAA CCTCACCCGGT CAAGTGATTC	720
ATGTTCCAGG TGATCCATCC TCTACTGCTT TCCCATTGGT TGCTGCCTTG CTTGTTCCAG	780
GTTCCGACGT CACCATCCTT AACGTTTGA TGAACCCAAC CGGTACTGGT CTCATCTTGA	840
CTCTGCAGGA AATGGGTGCC GACATCGAAG TGATCAACCC ACCTTCTGCT GGTGGAGAAG	900
ACGTGGCTGA CTTGGTGTGTT CGTTCTTCTA CTTTGAAGGG TGTTACTGTT CCAGAACGACC	960
GTGCTCCCTTC TATGATCGAC GAGTATCCAA TTCTCGCTGT TGCTGAGCTGCA TTGGCTGAAG	1020
GTGCTACCGT TATGAACGGT TTGGAAGAAC TCCGTGTAA GGAAAGCGAC CGTCTTTCTG	1080
CTGTCGCAAA CGGTCTCAAG CTCAACGGTG TTGATTGCGA TGAAGGTGAG ACTTCTCTCG	1140
TCGGTGGCTGG CCGTCCCTGAC GGTAAGGGTC TCGGTAACGC TTCTGGAGCA CCTGTCGCTA	1200

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CCCCACCTCGA TCACCGTATC GCTATGAGCT TCCCTGTTAT GGGTCTCGTT TCTGAAAAACC	1260
CTGTTACTGT TGATGATGCT' ACTATGATCG CTACTAGCTT CCCAGACTTC ATGGATTGGA	1320
TGGCTGCTCT TGGAGCTAAG ATCGAACTCT CCGACACTAA GGCTGCTTGA TGAGCTC	1377

## (2) INFORMATION FOR SEQ ID NO:10:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 318 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: double
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 87..317

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:10:

AGATCTATCG ATAAGCTTGA TGTAAATTGCA GGAAGATCAA AATTTTCAAT CCCCATTCCTT	60
CGATTGCTTC AATTGAAGTT TCTCCG ATG GCG CAA GTT ACC AGA ATC TGC AAT	113
Met Ala Gln Val Ser Arg Ile Cys Asn	
1 5	
CGT GTG CAG AAC CCA TCT CTT ATC TCC AAT CTC TCG AAA TCC AGT CAA	161
Gly Val Gln Asn Pro Ser Leu Ile Ser Asn Leu Ser Lys Ser Ser Gln	
10 15 20 25	
CCC AAA TCT CCC TTA TCG GTT TCT CTG AAG ACG CAG CAG CAT CCA CGA	209
Arg Lys Ser Pro Leu Ser Val Leu Lys Thr Gln Gln His Pro Arg	
30 35 40	
GCT TAT CCG ATT TCG TCG TCG TCG GGA TTG AAG AAG AGT GGG ATG ACG	257
Ala Tyr Pro Ile Ser Ser Ser Trp Gly Leu Lys Lys Ser Gly Met Thr	
45 50 55	
TTA ATT GGC TCT GAG CTT CGT CCT CTT AAG GTC ATG TCT TCT GTT TCC	305
Leu Ile Gly Ser Glu Leu Arg Pro Leu Lys Val Met Ser Ser Val Ser	
60 65 70	
ACG GCG TGC ATG C	
Thr Ala Cys Met	
75	

## (2) INFORMATION FOR SEQ ID NO:11:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 77 amino acids
  - (B) TYPE: amino acid
  - (D) TOPOLOGY: linear

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(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:11:

Met	Ala	Gln	Val	Ser	Arg	Ile	Cys	Asn	Gly	Val	Gln	Asn	Pro	Ser	Leu
1															15

Ile	Ser	Asn	Leu	Ser	Lys	Ser	Ser	Gln	Arg	Lys	Ser	Pro	Leu	Ser	Val
															30
20								25							

Ser	Leu	Lys	Thr	Gln	Gln	His	Pro	Arg	Ala	Tyr	Pro	Ile	Ser	Ser	Ser
35							40					45			

Trp	Gly	Leu	Lys	Lys	Ser	Gly	Met	Thr	Leu	Ile	Gly	Ser	Glu	Leu	Arg
50							55					60			

Pro	Leu	Lys	Val	Met	Ser	Ser	Val	Ser	Thr	Ala	Cys	Met			
65							70					75			

(2) INFORMATION FOR SEQ ID NO:12:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 402 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: double
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 87..401

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:12:

AGATCTATCG ATAAGCTTGA TGTAAATTGGA CGAACGATCAA AATTTTCATT CCCCATTCTT 60

CGATTGCTTC AATTGAAGTT TCTCCG ATG GCG CAA GTT AGC AGA ATC TGC AAT 113  
Met Ala Val Ser Arg Ile Cys Asn  
1 5GCT GTG CAG AAC CCA TCT CTT ATC TCC AAT CTC TCG AAA TCC ACT CAA 161  
Gly Val Gln Asn Pro Ser Leu Ile Ser Asn Leu Ser Lys Ser Ser Gln  
10 15 20 25CCC AAA TCT CCC TTA TCG GTT TCT CTG AAG ACG CAG CAG CAT CCA CGA 209  
Arg Lys Ser Pro Leu Ser Val Ser Leu Lys Thr Gln Gln His Pro Arg  
30 35 40GCT TAT CCG ATT TCG TCG TGG GGA TTG AAG AAG AGT GGG ATG ACG 257  
Ala Tyr Pro Ile Ser Ser Trp Gly Leu Lys Ser Gly Met Thr  
45 50 55

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(2) INFORMATION FOR SEQ ID NO:13:

#### (1) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 105 amino acids
  - (B) TYPE: amino acid
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:13:

Met Ala Gln Val Ser Arg Ile Cys Asn Gly Val Gln Asn Pro Ser Leu  
1 5 10 15

Ile Ser Asn Leu Ser Lys Ser Ser Cln Arg Lys Ser Pro Leu Ser Val  
20 25 30

Ser Leu Lys Thr Gln Gln His Pro Arg Ala Tyr Pro Ile Ser Ser Ser  
35 40 45

Trp Gly Leu Lys Lys Ser Gly Met Thr Leu Ile Gly Ser Glu Leu Arg  
50 55 60

Pro Leu Lys Val Met Ser Ser Val Ser Thr Ala Glu Lys Ala Ser Glu  
65 70 75 80

Gly Ser Lys Ser Leu Ser Asn Arg Ile  
100 105

(2) INFORMATION FOR SEQ ID NO:14:

**(i) SEQUENCE CHARACTERISTICS:**

- (A) LENGTH: 233 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: double
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

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## (ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 14..232

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:14:

AGATCTTTCA AGA ATG GCA CAA ATT AAC AAC ATG GCT CAA CGG ATA CAA Met Ala Gln Ile Asn Asn Met Ala Gln Gly Ile Gln	49
1 5 10	
ACC CTT AAT CCC AAT TCC AAT TTC CAT AAA CCC CAA GTT CCT AAA TCT Thr Leu Asn Pro Asn Ser Asn Phe His Lys Pro Gln Val Pro Lys Ser	97
15 20 25	
TCA ACT TTT CTT GTT TTT CGA TCT AAA AAA CTG AAA AAT TCA GCA AAT Ser Ser Phe Leu Val Phe Gly Ser Lys Lys Leu Lys Asn Ser Ala Asn	145
30 35 40	
TCT ATG TTG GTT TTG AAA AAA GAT TCA ATT TTT ATG CAA AAG TTT TGT Ser Met Leu Val Leu Lys Lys Asp Ser Ile Phe Met Gln Lys Phe Cys	193
45 50 55 60	
TCC TTT AGG ATT TCA GCA TCA GTG GCT ACA GCC TGC ATG C Ser Phe Arg Ile Ser Ala Ser Val Ala Thr Ala Cys Met	233
65 70	

## (2) INFORMATION FOR SEQ ID NO:15:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 73 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: protein

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:15:

Met Ala Gln Ile Asn Asn Met Ala Gln Gly Ile Gln Thr Leu Asn Pro 1 5 10 15	
Asn Ser Asn Phe His Lys Pro Gln Val Pro Lys Ser Ser Ser Phe Leu 20 25 30	
Val Phe Gly Ser Lys Lys Leu Lys Asn Ser Ala Asn Ser Met Leu Val 35 40 45	
Leu Lys Lys Asp Ser Ile Phe Met Gln Lys Phe Cys Ser Phe Arg Ile 50 55 60	
Ser Ala Ser Val Ala Thr Ala Cys Met 65 70	

## (2) INFORMATION FOR SEQ ID NO:16:

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- (I) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 352 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: double
  - (D) TOPOLOGY: linear

(II) MOLECULE TYPE: DNA (genomic)

- (ix) FEATURE:
- (A) NAME/KEY: CDS
  - (B) LOCATION: 49..351

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:16:

AGATCTGCTA GAAATAATT TGTAACTT TAAGAAGGAG ATATATCC ATG GCA CAA	57
Met Ala Gln	
1	
ATT AAC AAC ATG GCT CAA CGG ATA CAA ACC CTT AAT CCC AAT TCC AAT	105
Ile Asn Asn Met Ala Gln Gly Ile Gln Thr Leu Asn Pro Asn Ser Asn	
5  15	
TTC CAT AAA CCC CAA GTT CCT AAA TCT TCA ACT TTT CTT GTT TTT GGA	153
Phe His Lys Pro Gln Val Pro Lys Ser Ser Phe Leu Val Phe Gly	
20  35	
TCT AAA AAA CTG AAA AAT TCA GCA AAT TCT ATG TTG GTT TTG AAA AAA	201
Ser Lys Lys Leu Lys Asn Ser Ala Asn Ser Met Leu Val Leu Lys Lys	
40  50	
GAT TCA ATT TTT ATG CAA AAG TTT TGT TCC TTT AGG ATT TCA GCA TCA	249
Asp Ser Ile Phe Met Gln Lys Phe Cys Ser Phe Arg Ile Ser Ala Ser	
55  65	
GTG GCT ACA GCA CAG AAG CCT TCT GAG ATA GTG TTG CAA CCC ATT AAA	297
Val Ala Thr Ala Gln Lys Pro Ser Glu Ile Val Leu Gln Pro Ile Lys	
70  80	
GAG ATT TCA GGC ACT GTT AAA TTG CCT GGC TCT AAA TCA TTA TCT AAT	345
Glu Ile Ser Gly Thr Val Lys Leu Pro Gly Ser Lys Ser Leu Ser Asn	
85  95	
AGA ATT C	352
Arg Ile	
100	

(2) INFORMATION FOR SEQ ID NO:17:

- (i) SEQUENCE CHARACTERISTICS:
- (A) LENGTH: 101 amino acids
  - (B) TYPE: amino acid
  - (D) TOPOLOGY: linear

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(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:17:

Met	Ala	Dln	Ile	Asn	Asn	Met	Ala	Gln	Gly	Ile	Gln	Thr	Leu	Asn	Pro
1				5						10				15	

Asn	Ser	Asn	Phe	His	Lys	Pro	Gln	Val	Pro	Lys	Ser	Ser	Ser	Phe	Leu
			20					25						30	

Val	Phe	Gly	Ser	Lys	Lys	Leu	Lys	Asn	Ser	Ala	Asn	Ser	Met	Leu	Val
			35				40						45		

Leu	Lys	Lys	Asp	Ser	Ile	Phe	Met	Gln	Lys	Phe	Cys	Ser	Phe	Arg	Ile
			50			55							60		

Ser	Ala	Ser	Val	Ala	Thr	Ala	Gln	Lys	Pro	Ser	Glu	Ile	Val	Leu	Gln
65					70					75				80	

Pro	Ile	Lys	Glu	Ile	Ser	Gly	Thr	Val	Lys	Leu	Pro	Gly	Ser	Lys	Ser
			85					90					95		

Leu	Ser	Asn	Arg	Ile											
			100												

(2) INFORMATION FOR SEQ ID NO:18:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 28 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:18:

Xaa	His	Gly	Ala	Ser	Ser	Arg	Pro	Ala	Thr	Ala	Arg	Lys	Ser	Ser	Gly
1				5					10				15		

Leu	Xaa	Gly	Thr	Val	Arg	Ile	Pro	Gly	Asp	Lys	Met				
			20					25							

(2) INFORMATION FOR SEQ ID NO:19:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 13 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

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## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:19:

1	Ala Pro Ser Met Ile Asp Glu Tyr Pro Ile Leu Ala Val	10
	5	

## (2) INFORMATION FOR SEQ ID NO:20:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 15 amino acids
- (B) TYPE: amino acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:20:

1	Ile Thr Gly Leu Leu Glu Gly Glu Asp Val Ile Asn Thr Gly Lys	15
	5	

## (2) INFORMATION FOR SEQ ID NO:21:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 17 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:21:

ATGATHGAYG ARTAYCC

17

## (2) INFORMATION FOR SEQ ID NO:22:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 17 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:22:

GARGAYGTNA THAACAC

17

## (2) INFORMATION FOR SEQ ID NO:23:

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- (1) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 17 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:23:

GARGAYGTNA THAATAC

17

(2) INFORMATION FOR SEQ ID NO:24:

- (1) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 38 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:24:

CGTGGATAGA TCTAGGAAGA CAACCATGGC TCACGGTC

38

(2) INFORMATION FOR SEQ ID NO:25:

- (1) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 44 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:25:

GGATAGATTA AGGARGACGC GCATGCTTCA CGGTGCAAGC AGCC

44

(2) INFORMATION FOR SEQ ID NO:26:

- (1) SEQUENCE CHARACTERISTICS:  
(A) LENGTH: 35 base pairs  
(B) TYPE: nucleic acid  
(C) STRANDEDNESS: single  
(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

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(xi) SEQUENCE DESCRIPTION: SEQ ID NO:26:

GGCTGCCCTGA TGAGCTCCAC AATGCCCATC GATGG

35

(2) INFORMATION FOR SEQ ID NO:27:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 32 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:27:

CGTCGCTCGT CGTGCCTGGC CGCCCTGACG GC

32

(2) INFORMATION FOR SEQ ID NO:28:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 29 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:28:

CGGGCAAGGC CATCCAGGCT ATGGGGGCC

29

(2) INFORMATION FOR SEQ ID NO:29:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 31 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:29:

CGGGCTGCCCG CCTGACTATG GGCCCTCGTCG G

31

(2) INFORMATION FOR SEQ ID NO:30:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 15 amino acids
- (B) TYPE: amino acid

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- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear
- (ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:30:

Xaa His Ser Ala Ser Pro Lys Pro Ala Thr Ala Arg Arg Ser Glu  
1 5 10 15

(2) INFORMATION FOR SEQ ID NO:31:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 17 base pairs
  - (B) TYPE: nucleic acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:31:

CCGGCTBGCSCG CYTTSGG

17

(2) INFORMATION FOR SEQ ID NO:32:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 16 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:32:

Pro Gly Asp Lys Ser Ile Ser His Arg Ser Phe Met Phe Gly Gly Leu  
1 5 10 15

(2) INFORMATION FOR SEQ ID NO:33:

- (i) SEQUENCE CHARACTERISTICS:
  - (A) LENGTH: 13 amino acids
  - (B) TYPE: amino acid
  - (C) STRANDEDNESS: single
  - (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: peptide

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## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:33:

Leu	Asp	Phe	Gly	Asn	Ala	Ala	Thr	Gly	Cys	Arg	Leu	Thr
1				5					10			

## (2) INFORMATION FOR SEQ ID NO:34:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 26 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:34:

CGGCAATCCC GCCACCGGGCG CGGCC

26

## (2) INFORMATION FOR SEQ ID NO:35:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 49 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:35:

GGACGGCTGC TTGCACCGTG AAGCATGCTT AAGCTTGGCG TAATCATGG

49

## (2) INFORMATION FOR SEQ ID NO:36:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 35 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

## (ii) MOLECULE TYPE: DNA (genomic)

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:36:

GGAAGACGCC CAGAATTCAC GGTGCAAGCA GCCGG

35

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Claims:

1. An isolated DNA sequence encoding an EPSPS enzyme having a  $K_m$  for phosphoenolpyruvate (PEP) between 1-150  $\mu\text{M}$  and a  $K_i(\text{glyphosate})/K_m(\text{PEP})$  ratio between 3-500, which DNA sequence is capable of hybridizing to a DNA probe from a sequence selected from the group consisting of SEQ ID NO:2, SEQ ID NO:4, and SEQ ID NO:6.
- 10 2. A DNA molecule of claim 1 wherein said  $K_m$  for phosphoenolpyruvate is between 2-25  $\mu\text{M}$ .
- 15 3. A DNA molecule of claim 1 wherein said  $K_i/K_m$  ratio is between 6-250.
- 20 4. An isolated DNA sequence encoding a protein which exhibits EPSPS activity wherein said protein is capable of reacting with antibodies raised against a Class II EPSPS enzyme.
- 25 5. The DNA sequence of Claim 4 wherein said protein is capable of reacting with antibodies raised against a Class II EPSPS enzyme selected from the group consisting of SEQ ID NO:3, SEQ ID NO:5, and SEQ ID NO:7.
- 30 6. The DNA sequence of Claim 5 wherein said antibodies are raised against a Class II EPSPS enzyme of SEQ ID NO:3.
7. A recombinant, double-stranded DNA molecule comprising in sequence:

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- a) a promoter which functions in plant cells to cause the production of an RNA sequence;
  - b) a structural DNA sequence that causes the production of an RNA sequence which encodes a Class II EPSPS enzyme; and
  - c) a 3' non-translated region which functions in plant cells to cause the addition of a stretch of polyadenyl nucleotides to the 3' end of the RNA sequence
- 10 where the promoter is heterologous with respect to the structural DNA sequence and adapted to cause sufficient expression of the fusion polypeptide to enhance the glyphosate tolerance of a plant cell transformed with said DNA molecule.
- 15 8. The DNA molecule of Claim 7 in which said structural DNA sequence encodes a fusion polypeptide comprising an amino-terminal chloroplast transit peptide and a Class II EPSPS enzyme.
- 20 9. The DNA molecule of Claim 8 wherein said structural DNA sequence encoding a Class II EPSPS enzyme is selected from the group consisting of SEQ ID NO:2, SEQ ID NO:4 and SEQ ID NO:6.
- 25 10. The DNA molecule of Claim 9 wherein said sequence is from SEQ ID NO:2.
11. A DNA molecule of Claim 8 in which the promoter is a plant DNA virus promoter.

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12. A DNA molecule of Claim 11 in which the promoter is selected from the group consisting of CaMV35S and FMV35S promoters.

5 13. A method of producing genetically transformed plants which are tolerant toward glyphosate herbicide, comprising the steps of:

- 10 a) inserting into the genome of a plant cell a recombinant, double-stranded DNA molecule comprising:
- 15 i) a promoter which functions in plant cells to cause the production of an RNA sequence,
- ii) a structural DNA sequence that causes the production of an RNA sequence which encodes a fusion polypeptide comprising an amino terminal chloroplast transit peptide and a Class II EPSPS enzyme,
- 20 iii) a non-translated DNA sequence which functions in plant cells to cause the addition of a stretch of polyadenyl nucleotides to the 3' end of the RNA sequence

where the promoter is heterologous with respect to the structural DNA sequence and adapted to cause sufficient expression of the fusion polypeptide to enhance the glyphosate tolerance of a plant cell transformed with said gene;

- 25 b) obtaining a transformed plant cell; and
- c) regenerating from the transformed plant cell a genetically transformed plant which has increased tolerance to glyphosate herbicide.

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& DATE

14. The method of Claim 13 wherein said structural DNA sequence encoding a Class II EPSPS enzyme is selected from the group consisting of SEQ ID NO:2, SEQ ID NO:4, and SEQ ID NO:6.

5

15. The DNA molecule of Claim 14 wherein said sequence is that as set forth in SEQ ID NO:2.

10 16. A method of Claim 13 in which the promoter is from a plant DNA virus.

15 17. A method of Claim 16 in which the promoter is selected from the group consisting of CaMV35S and FMV35S promoters.

15

18. A glyphosate tolerant plant cell comprising a DNA molecule of Claims 8, 9 or 12.

20 19. A glyphosate tolerant plant cell of Claim 18 in which the promoter is a plant DNA virus promoter.

20 20. A glyphosate tolerant plant cell of Claim 19 in which the promoter is selected from the group consisting of CaMV35S and FMV35S promoters.

25

21. A glyphosate tolerant plant cell of Claim 18 selected from the group consisting of corn, wheat, rice, soybean, cotton, sugarbeet, oilseed rape, canola, flax, sunflower, potato, tobacco, tomato, alfalfa, poplar, pine, apple and grape.

30

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22. A glyphosate tolerant plant comprising plant cells  
of Claim 18.

5        23. A glyphosate tolerant plant of Claim 22 in which  
the promoter is from a DNA plant virus promoter.

10      24. A glyphosate tolerant plant of Claim 23 in which  
the promoter is selected from the group consisting of CaMV35S  
and FMV35S promoters.

15      25. A glyphosate tolerant plant of Claim 22 selected  
from the group consisting of corn, wheat, rice, soybean, cotton,  
sugarbeet, oilseed rape, canola, flax, sunflower, potato, tobacco,  
tomato, alfalfa, poplar, pine, apple and grape.

20      26. A method for selectively controlling weeds in a  
field containing a crop having planted crop seeds or plants  
comprising the steps of:

25      a) planting said crop seeds or plants which are  
glyphosate tolerant as a result of a recombinant  
double-stranded DNA molecule being inserted  
into said crop seed or plant, said DNA molecule  
having:

- 30      i) a promoter which functions in plant cells to cause  
the production of an RNA sequence,  
ii) a structural DNA sequence that causes the  
production of an RNA sequence which encodes a  
polypeptide which comprises an amino terminal  
chloroplast transit peptide and a Class II EPSPS  
enzyme,

iii) a 3' non-translated DNA sequence which functions in plant cells to cause the addition of a stretch of polyadenyl nucleotides to the 3' end of the RNA sequence

5 where the promoter is heterologous with respect to the structural DNA sequence and adapted to cause sufficient expression of the fusion polypeptide to enhance the glyphosate tolerance of a plant cell transformed with said gene; and

10 b) applying to said crop and weeds in said field a sufficient amount of glyphosate herbicide to control said weeds without significantly affecting said crop.

27. The method of Claim 26 wherein said structural  
15 DNA sequence encoding a Class II EPSPS enzyme is selected from the sequences as set forth in SEQ ID NO:2, SEQ ID NO:4 or SEQ ID NC:6.

28. A method of Claim 27 in which said DNA  
20 molecule contains a structural DNA sequence from SEQ ID NO:2.

29. A method of Claim 28 in which said DNA molecule further comprises a promoter selected from the group consisting of the CAMV35SS and FMV35S promoters.

25 30. A method of Claim 29 in which the crop plant is selected from the group consisting of corn, wheat, rice, soybean, cotton, sugarbeet, oilseed rape, canola, flax, sunflower, potato, tobacco, tomato, alfalfa, poplar, pine, apple and grape.

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## Ssp I

6358	TCATCAAATTTAGCAGGCATTCCAGATGGGTCAATCAACAAAGGTACGAGCCATATC AGTAGTTTATAATCGTCGTAAGGTCTAACCCAAGTTAGTTAGTTGTTCCATGGCTCGGTATAG	6417
6418	ACTTTATTCAAAATTGGTATCGGCCAAAACCAGAAGGAACACTCCCATTCCCTCAAAGGTTGTA TGAATAAAGTTAACCATAGCGGGTTGGTTCTCCCTGAGGGTAGGAGTTCCAAACAT	6477
6478	AGGAAGAAATTCTCAGTCCAAAGCCTAACAAAGGTACAGGTACAGAGTCTCCAAACCATA TCCTTCTTAAGAGTCAGGTTCCAGTCCATGTTCAAGGTTGGTAAT	6537
6538	GCCAAAAGCTACAGGAGATCAATGAAGAATCTTCAATCAAAGTAACACTACTGTTCCAGCA CGGTTTCGATGTCCTCTAGTTACTCTTAGAAGTTAGTTCAATTGATGACAAGGTGTT	6597
6598	CATGGCATCATGGTCAGTAAGTTTCAGAAAAAGACATCCACCGAAGACTTAAAGTTAGTGG GTACGGTAGTACCGTCATCAAAGTCTTTCTGTAGGTGGCTCTGAATTCAATCACCA	6657
6658	GCATCTTTGAAGTAATCTTGTCAACATCGAGCAGCTGGCTTGTTGGACAGACAAAAA CGTAGAAACTTCAATTAGAACAGTTGAGCTGTCGACCGAACACCCCTGGTCTGTTTT	6717

FIG. 1

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6718	AGGAATGGCAGAATTGTTAGGGCACCTACCAAAAGCATCTTGCCTTATTGCCAAAG TCCTTACCACTGTCTTAACAATCCGGTGGATGGTTTCGTAGAAACGGAAATAACGTTTC	6777
6778	ATAAAGCAGATTCCCTCTAGTACAAGTGGGAACAAATAACGTGGAAAGAGCTGCCCTG TATTTCGTCTAAGGAGATCATGGTTCACCCCTTGTTTATTGCACCTTCTCGACAGGAC	6837
6838	ACAGCCCACCTCACTATGGGTAGCGAACGACGACTAACAAAGAATTCCCTCTA TGTGGGTAGTGATTAACGCATACTGCTGGTCACTGGTGTCTTAAGGGAGAT	6897
	SspI	
6898	TATAAAGGGCATTCAATTCCATTGAAGGGATCATCAGATACTAACCAATTTCCTC ATATTCTTCGTAAGTAAGGGAAACTCCTAGTAGTCTATGTTAGGTATAAAAGAG	6954

FIG. 1 (cont.)

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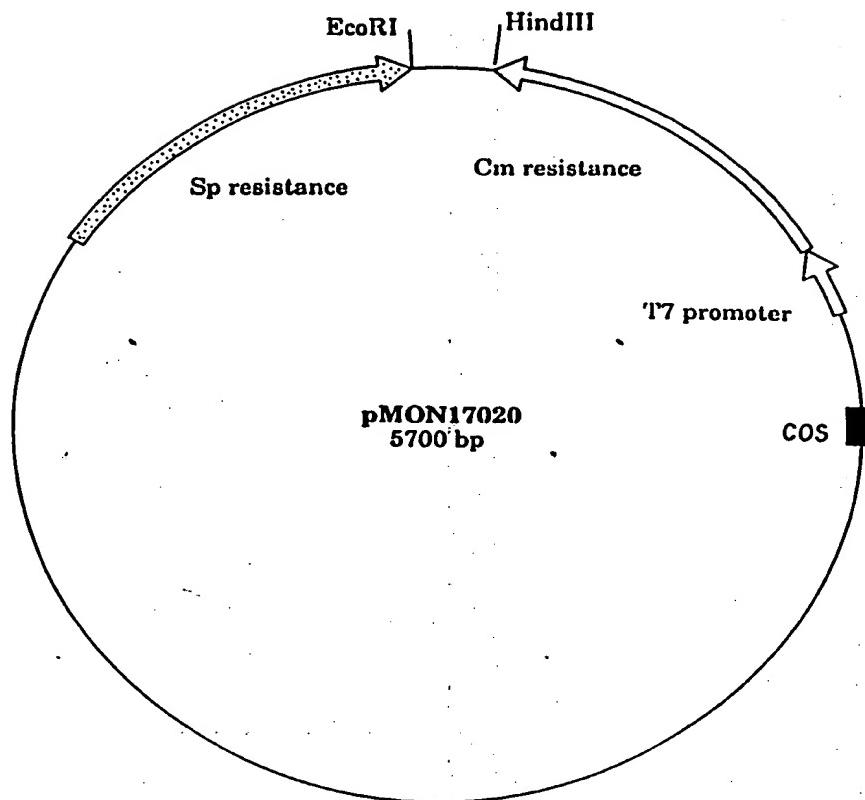


FIG. 2

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1 AAGCCCCGGTTCTCCGGCGCTGGAGAGCCGGTGGATAGATTAAAGGAAGGACGCC  
 61 CATGTGCACGGTGCAGGCCGGCAACGGCCGGCAATCCTCTGGCCCTTCGGG  
 M S H G A S S R P A T A R K S S G L S G  
 (FMet)

121 AACCGTCCGCATTCCGGACAAGTCGATCTCCACCGGTCTCATGGTGGGGTCT  
 T V R I P G D K S I S H R S F M F G G L

181 CGCGAGGGTGAACACGGGCATCACCGGCCCTCTGGAAAGGGAGGTCAATACGGG  
 A S G E T R I T G L L E D V I N T G

241 CAAGGCCATGGGGCCATGGGCCAGGATCCGTAAAGGAAGGGAGACACCTGGATCATCGA  
 K A M Q A M G A R I R K E G D T W I I D

301 TGGCGTCGGCAATGGGGCCTCCTGGCCCTGAGGGCGCGCTCGATTTCGGCAATGCC  
 G V G N G G L L A P E A P L D F G N A A  
 NcoI

361 CACGGGGCTGGCCGTGACCATGGGGCTCGTGGGGTCTACGATTTCGACAGGCCCTCAT  
 T G C R L T M G L V G V Y D F D S T F I

421 CGGGGACGCCCTCGCTCACAAAGGCCGATGGGCCGGTGTGAACCCGGCTGGCGAAAT  
 G D A S L T K R P M G R V L N P L R E M

481 GGGCGTGCAGGTGAATCGGAAGAACGGTGACCGTCTCCGGTACCTTGGCGGGCGAA  
 G V Q V K S E D G D R L P V T L R G P K

541 GACGGCCGACGGCGATCACCTAACCGGTGCCGATGGCCTCCGCACAGGTGAAGTCCGGT  
 T P T P I T Y R V P M A S A Q V K S A V

601 GCTGCTGGCCGGCTCAACACGGCCGGCATCACGACGGTCATCGAGGCCATCATGGACGGC  
 L L A G L N T P G I T T V I E P I M T R

BamHI

ClAI

FIG. 3a

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661 CGATCATACGAAAGATGCTGCAGGGCTTGGGCCAACCTTACCGTCGAGACGGATGC  
 D H T E K M L Q G F G A N L T V E T D A  
 SacII

721 GGACGGGTGCCACCATCCGGCTGGAAAGGCCAACGCTCACCGGCCAAGTCATCGA  
 D G V R T I R L E G R G K L T G Q V I D  
 CGTGGCGGGCGAACCCCGTCTCGACGGCTTCGGCTGGTGGGCCCTGCTTGTCCGGG  
 V P G D P S S T A F P L V A A L L V P G

781 CTCGGACGTCACCATCCTCAACGTTGATGAACCCCCACCCGCACGGCTCATCTGAC  
 S D V T I L N V L M N P T R T G L I L T  
 GCTGCAGGAATGGGGCCGACATGAACTCATCAACCCGGCCCTGGCGGGCGGAAGA

841 L Q E M G A D I E V I N P R . L A G G E D  
 CGTGGGGACCTGGCTTGCCTCCACGCTGAAGGGGTCAAGGGTGGAAAGACCG

901 V A D L R V R S S T L K G V T V P E D R  
 CGCGCTTCGATGATCGACGAATATCGATTCTCGCTGTGCCGCCCTCGGAAAGG

961 A P S M I D E Y P I L A V A A F A E G  
 -----

1021 1081 1141 1201 1261 1321 1381

1081 GGCACCGTGTGAAACGGCTGGAAAGAACTCCGGTCAAGGAAGGGACCGGCCCTCGGC  
 A T V M N G L E E L R V K E S D R L S A  
 CGTCGCCAATGGCCTCAAGCTCAATGGCGGATTGGGATGAGGGGGAGACGTCGCTCGT  
 V A N G L K L N G V D C D E G E T S L V  
 CGTGGCGGGCCGCCCTGACGGCAAGGGGCTCGGCAACGGCTCGGGCGCCGCGCAC  
 V R G R P D G K G L G N A S G A A V A T  
 CCATCTCGATACCGCATGCCATGCTCGTCACTGGGCCCTCGTGTGGAAACCC  
 H L D H R I A M S F L V M G L V S E N P  
 TGTCACGGTGGACGATGCCACGATGCCAGGCTTCGGAGATCATGGACCTGAT  
 V T V D D A T M I A T S F P E F M D L M  
 GGCACGGCTGGGGCAAGATCGAACTCTCGATACGAAAGGCTGACCTTCACA  
 A G L G A K I E L S D T K A A \* \* ↑  
 FIG. 3b

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1441 ATCGCCATCGATGGTCCCCTGGCTGGCCGCCAAGGGGACGGCTCTCGCCGCCGTATGGCCGAG  
1501 GTCTATGGCTTTCATCATCTCGATACGGGCCCTGACCTATCGCGCCACGGCCAAAGGGCTG  
1561 CTCGATCGCGGCCCTGTCGGCTTGAATGACGAGGCCTGATGGCCGATGTCGGCCAACTCTC  
1621 GATCTTGCCGGGCTGACCGGGTGGCTGCTGCTGGCCCATGGCCATGGCCATTGGCCGTTTCG  
1681 AAGATCGGGGTCAATGCCCTCGGTGCGGGGGCGCTGGTCAAGGGCAGGCCAGCTTGGC  
1741 GCGCGGTGAGGCCGGCACGGTGGATGGACGGATATGGCACCGTTGGTCTGGCCGGAT  
1801 GGGCGGTGAAGGCTCATATGTCACCGGGTCAACGGGAAGTGGCGGAAACGGCTATGAC  
1861 GAAATCCTGGCAATGGGGGTGGCCGATACGGGACGATCCCTGGAGGATACTGGGGCC  
1921 CGCGAGCGGGACATGGTGGGGACAGTCCTTGAAGCCCCGAGCTGGCAC  
1981 TT

FIG. 3c

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1	GTAGCCACACATAATTACTATAGCTAGGAAGCCCCGCTATCTCTCAATCCC GGCGT GAT CGC	60
61	GCCAAATGTGACTGTGAAAATCCATGTCCTCATTCGATCCCCAAACCAGCAACCGC	120
121	CGGGCGCTGGGGCACTCACGGGGAAATCCGCATTCCGGCATTCGATCTCGCA	180
	R R S E A L T G E I R I P G D K S I S H	
181	TGGCTTCTTCATGGGGTCTGCATCGGGGAAACCCGCATCACGGGCTTCTGGA	240
	R S F M F G L A S G E T R I T G L L E	
241	AGGGAGGACGTCATCAATAACAGGCCGCCATGCAGGCCATGGGGCGAATACTCGTAA	300
	G E D V I N T G R A M Q A M G A K I R K	
301	AGAGGGCGATGCTGGATCATCAACGGGCTGGCAATGGCTGGCTGGAGCCGAAAGC	360
	E G D V W I N G V G N G C L L Q P E A	
361	TGGCTCGATTGGCCAATGCCGGAACCGGGGGCGGCCCTCACCATGGGCCTTGTCGGCAC	420
	A L D F G N A G T G A R L T M G L V G T	
421	CTATGACATGAAGACCTCTTTATGGCGACGCCCTGGCTGCGAAGGGCCGATGGCCG	480
	Y D M K T S F I G D A S L S K R P M G R	
481	CGTGCTGAACCGGTTGGCGAAATGGCGTTACGGTGGAAAGCAGCCGATGGCGACCGCAT	540
	V L N P L R E M G V Q V E A A D G D B M	
541	GCCGGCTGACGGCTGATCGGGCCGAAGACGGCAAATCCGATCACCTATGGCTCCGATGGC	600
	P L T L I G P K T A N P I T Y R V P M A	
601	CCTCCGGCAGGTAATCCGCCGTTGCTGGCCGGTCTCAACACGCCGG3CGTCACCAAC	660
	S A Q V K S A V L L A G L N T P G V T T	
661	CGTCATCGAGCCGGTCATGACCCGGACCAACCGAAAPAGATGGCTGCAGGGCTTGGCG	720
	V I E P V M T R D H T E K M L Q G F G A	
721	CGACCTCAGGGTGGAGACCGACAAGGATGGCTGGCCATATCCGCATACGGGCAAGG	780
	D L T V E T D K D G V R H I T G Q G	
781	CAAGCTTGTGGCCAGACCATCGACGCTGGCGATCCGGCTCATGACCGCCCTCCGGCT	840
	K L V G Q T I D V P G D P S S T A F P L	

FIG. 4

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841	CGTTGCCCTCTGGGAAGGTCCGACGTACCATTCCGAAACGTGCTGATGAA	900
	V A L V E G S D V T I R N V L M N P	960
901	GACCGTACCGGCTCATCCTCACCTTGAGGAATGGGGGATATCGAAGTGGCTCAA	
	T R T G L I L T L Q E M G A D I E V L N	1020
961	TGCCCCGTCTTGAGGGGGAAAGACGTCGGCGATCTGGCGTCAAGGCTTCGAAGTCAA	
	A R L A G G E D V A D L R V R A S K L K	1080
1021	GGGCGTCTCGTCTCCGGCGAACGTTGGCCGATGATGATCGACGAATATCCGGTCTGGC	
	G V V P P E R A P S M I D E Y P V L A	1140
1081	GATTGCCGCCTCTCGGGAAAGGGGAAACCGTGTATGGACGGGCTCGACGAACTGGCGT	
	I A S F A E G E T V M D G L D E L R V	1200
1141	CAAGGAATGGATCGTCTGGCAGGGTTCGACGGGCTTGAAGCCAACGGGTCGATG	
	K E S D R L A A V A R G L E A N G V D C	1260
9211201	CACCGAAGGGAGATGTCGGTGAACGGTTGGGGCCCGACGGCAAGGGACTGGCGG	
	T E G E M S L T V R G R P D G K G L G	1320
1261	CGGCACCGGTTGCAACCCATCTCGATCATCGTATCGGATGAGCTTCCTCGTGA	
	G T V A T H L D H R I A M S F L V M G L	1380
1356	TGGGGAAAAGCCGGTGAACGGTTGACGACAGTAACATGATGCCACGTCCTCCCAGA	
	A A E K P V T V D D S N M I A T S F P E	1440
1381	ATTATGGACATGATGCCGGGATTGGGGCAAAAGATCGAGTTGAGCTACTCTAGTC	
	F M D M M P G L G A K I E L S I L	1500
1441	CGACAGGGAAATAATTATTGGCAGATTACCGGTGGTCTAGGGGGT	
1501	TTAATGTCCAAATCTCCATACGTAACAGCATCAGGAAATATCAA	1560
1561	ATTGGCTAGAGCAAGCGAGCCGGGATCAATTGACTTCATTCTGAGAAATTGGCCTCGCA	1620
1621	TCCCCGGGGTCCGGGGATCAATTGACTTCATTCTGAGAAATTGGCCTCGCA	1673

FIG. 4 (cont.)

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1	GTGATCGGCCAATAATGTGACTGTGAAAAATCCATGTCCCATTCTGCATCCCCGAACCA	60
61	GCAACCGCCCGCCGGCTCGGAGGGCACTCACGGGAAATCCGGATTCCGGCATTCGGCAAGTCC	120
A T A R R S E A L T G E I R I P G D K S		
121	ATCTCGCATCGCTCTTCATGTTGGGGTCTCGCATCGGGGAAACCCGCATCACCAGGC	180
I S H R S F M F G G L A S G E T R I T G		
181	CTTCTGGAAGGGCAGGACGTCAATAACAGGCCGCCATGGCAGGCCATGGCGCGAAA	240
L L E G E D V I N T G R A M Q A M G A K		
241	ATCCGTAAGGGCCGATGGATCATCAACGGCGTCCGGCAATGGCTGCCTGTGCAG	300
I R K E G D V W I I N G V G N G C L L Q		
301	CCCGAAGCTGGCTCGATTTCGGCAATGCCGGAACCGGGCGCCCTCACCATGGGCCCT	360
P E A A L D F G N A G T G A R L T M G L		
361	GTCGGCACCTATGACATGAAAGACCTCTTATCGGCCGACGCCCTCGCTGTGAAAGGCCCG	420
V G T Y D M K T S F I G D A S L S K R P		
421	ATGGGCCCGCTGCTGAACCCGTTGGCGAAATGGCGTTACGGTGGAAAGCAGCCGATGGC	480
M G R V L N P L R E M G V Q V E A A D G		
481	GACCGCATGGCCGGTGTACGGTGTATGGGGCGAACGGCCAAATCCGATCACCTATGGGTG	540
D R M P L T L I G P K T A N P I T Y R V		
541	CGCATGGCTCCGGCAGGTAAATCCGGCGTGTGGCTGCCGGTCTCAACACGCCGGGC	600
P M A S A Q V K S A V L L A G L N T P G		
601	GTCACCAACCGTCAATCGAGCCGGTCAATGACCCGGGACACCCGAAAAGATGGCTGCAGGGC	660
V T T V I E P V M T R D H T E K M L Q G		
661	TTTGGCGCCGACCTCACGGTGTGAGACCGACAAGGATGGCTGCCATATCCGCATCAC	720
F G A D L T V E T D K D G V R H I R I T		
721	GGCCAGGGCAAGCTTGTCGGCCAGACCATCGACGTGGCGGATCGTCAATCGACCGGC	780
G Q G K L V G Q T I D V P G D P S S T A		
781	TTCGGCTCGTTGGGGCTTCTGGTGGAAAGGTTCGGACGTCAACCGTGTGCT	840
F P L V A A L L V E G S D V T I R N V L		

FIG. 5

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841	ATGAAACCGAACCGTACCGGCCTCATCCTCACCTTGAGGAAATGGGCCGATATCGAA	900
M N P T R T G L I L T L Q E M G A D I E		
901	GTGCTCAATGCCCGTCTTGAGGGCGAAGACGTCGCCGATCTGGCGTCAAGGGCTTCG	960
V L N A R L A G G E D V A D L R V R A S		
961	AAGCTCAAAGGGCGTGTCTCCGCCCGAACGTCGCCGTCGATGATCGACGAATAATCG	1020
K L K G V V P P E R A P S M I D E Y P		
1021	GTCCTGGCGATTGGCCCTCCCTTGAGGGAAAGGGCAAAACCGTGTGGACGGCTCGACGAA	1080
V L A I A S F A E G E T V M D G L D E		
1081	CTGCGCTCAAGGAATCGGATCGTCTGGAGCCGGTGGCAGCGGTGCAACGGCCAACGGC	1140
I R V K E S D R L A A V A R G L E A N G		
1141	GTCGATTCGACCGAACGGGAGATGCTGCGCTGACGGTTGGCGGGCCGACGGCAAGGGAA	1200
V D C T E G E M S L T V R G R P D G K G		
1201	CTGGGGGGGGCACGGTGGCAACCCATCTGGATCATCGTATCGGATGAGCTTCCTCGTG	1260
L G G G T V A T H I D H R I A M S F L V		
1261	ATGGGGCTTGCGGGAAAAGCCGGTGAACGAGTAACATGATGTCGCCACGTC	1320
M G L A E K P V T V D D S N M I A T S		
1321	TTCGGGAATTGACATGATGCCGGGATGGGGCAAAAGATCGAGTTGAGCATACTC	1380
F P E F M D M M P G L G A K I E L S I L		
1381	TAGTCACTCGACAGCGAAATAATTGGCAGGATTGGCCATTATTACCGGTTGGTCTCA	1440
1441	GGGGGGTTAAATGTCCCATCTTCCATACGTAACAGCATCAGGAATAATCAAAAGCTT	1500

FIG. 5 (cont.)

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3	S LTQPIARVDGTINLPGSKTVSNRALLAALAHGKTVLTLNLLDSDDDV RH	52
9	P ATARKSSGSLSGTVRIPGDKSISHRSEMFGLASGETRITGLEGEDDV IN	58
53	M LNALTALGVSYTTSADRTRCEIIGNGGPLHAEAGALEFLGNAGTAMRPL	102
59	T GKA M QAMG A RIRKE D T W I I D C V G N G G L I A P E A P I D .. F G N A A T G C R L T	106
103	A A A L C L G S N D I V L T G E P R M K E R P I G H L V D A L R L G G A K I T Y L E Q E N Y P P L R	152
107	M GLVGVYDFDSTFIGDASLT K R P M G R V L N P L R E M G V Q V K . S E D G D R L P V T	155
153	L Q G G F T G G N N D V D G S V S S Q F L T A L I M T A P A E D T V I R I K G D L V S K P Y I D	202
156	L R G P K T P T P I T Y R V P M A S A Q V K S A V V L A G L N T P G I T T V I E P I M T R D H T E K	205
203	I T I N L M K T F G V E I E N Q H Y Q Q F V V K G G Q S Y Q S P G T Y L V E G D A S S A S Y F L A A	252
206	M I Q G F G A N L T V E T D A D G V R T I R L E G R K I L T G Q V I D V P G D P S S T A F P L V A A A	255
253	A A I K G G T V K V T G I G R N S M Q G D I R F A D V L E R M G A T I .. . C W G D D Y ..	293
256	L L V P G S D V T I L N V I M N P T R T G L I L T .. L Q E M G A D I E V I N P R I L A G G E D V A D	303
294	I S C T R G E L N A I D M D M N H I P .. . D A A M T I A T A A L F A K G T T R L R N I Y N W R V K	340

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FIG

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304 LVRSSSTLKGVTVPEDRAPSMDYEPILVAAAFAGATVMNGLEELRVK 353  
341 ETDRLFAMATELRKVGAEEVEGHDYIRI.TPPEKLFN.....AEIATYND 384  
|.||| |:|.:| |::| |:| |:| |:| |:| |:| |:| |:| |:| |:| |:| |:  
354 ESDRLSAVANGLKNGVDCEGETSLVVRGRPDGKGLGNASGAAVATHLD 403  
|.  
385 HRMAMCFSLVAL.SDTPVTLIDPKCTAKTFPDYFEQLARISQ 425  
|:|:| |::| |:| |:| |:| |:| |:| |:| |:| |:| |:| |:| |:  
404 HRIAMSFLLVMGLVSENPNPTVDDATMIATSPEFMIDL MAGLGA 445

FIG. 6 (cont.)

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1 MSHGASSRPATARKSSGLSGTWRIPGDKSISSHRSFMGGLASGETRITGL 50  
 1 ||| : || . : || | : | . : | : | | | | | | | | | | | | | | | |  
 1 MSHSASPRAKATARRSEALTGEIRIPGDKSISSHRSFMGGLASGETRITGL 50

51 LEGEDVINTGKAMQAMGARIRKEGDTWIDGVGNGLLAPEALDFGNAA 100  
 1 ||| : || | | | : | | | | : | | | | | | | | | | | | | | | | | |  
 51 LEGEDVINTGRAMQAMGAKIRKEGDTWINGVGNGLLQPEALDFGNAG 100

101 TGCRLTMGLVGVYDEFDSTFIGDASLTKPRMGRVLNPLREMGVQVKSEDDG 150  
 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  
 101 TGARLTMGLVGTYDMKTSFIGDASLSKPRMGRVLNPLREMGVQEADDG 150

151 RLPVTLRGPKTPPI TYRVPMASAQVKSAVLLAGLNTPGITTVIEPIMTR 200  
 1 | : | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  
 151 RMPLTLIGPKTANPITYRVPMASAQVKSAVLLAGLNTPGVTTVIEPVMT 200

201 DHTEKMLQGFGANLTIVETDAGVRTRIREGRGKLTGQVIDVPGDPSSSTA 250  
 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  
 201 DHTEKMLQGFEGADLTIVETDKDGVHRIRITGQGKLVGTIDVPGDPSSTA 250

251 PLVAALLVPGSDVTILNVLMNPTRTGLLTIQEMGADIEVINPLAGGED 300  
 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |  
 251 PLVAALLVEGSDVTIRNVLMNPTRTGLLTIQEMGADIEVLNARLAGGED 300

FIG. 7

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301 VADLRVRSSTLKGVTVPEDRAPSMDIEYPILAVAAFAEGATVMNGLEEL 350  
| | | | . | | | . | | | | : | | : | | | | : | | : | | |  
301 VADLRVRAVKLKGVVPPERAPSMDIEYPVLIAASFAEGETVMGGLDEL 350

351 RVKESDRLLSAVANGLKLNGVDCDCDEGETSLVVRGRPDGKGGLGNASGAAVAT 400  
| | | | . | | | . | | | | : | | : | | | | : | | : | | |  
351 RVKESDRLLAAVARGLLEANGVDCTEGEMSLTVRGRPDGKGGLG...GGTVAT 397

401 HLDHRIAMSFLVMGLVSENPVTVDDATMIATSPEFMDIMAGLGAKIELS 450  
| | | | | | | . | | | | . | | | | | | | | : | | | | | | |  
398 HLDHRIAMSFLVMGLAAEKPVTVDDSMIATSPEFMDMMPGLGAKIELS 447

FIG. 7 (cont.)

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1 CCATGGCTCACCGGTGCAAGCAGCCGTCCAGCAAAC TGCTCGTAAGTCTCTGGTCTTTCTG 60  
 61 GAACCGTCCGTATTCCAGGTGACAAGTCTATCTCCCACAGGTCTCATGGTGGGGTC 120  
 121 TCGCTAGGGTGAACACTGTTACCCGGTCTTTGGAAAGGTGAAGATGTTATCAACACTG 180  
 181 GAAAGGCTATGCCAACGCTATGGGTGCCAGAATCCGTAAGGAAGGTGATACTTGATCATTG 240  
 241 ATGGGTGTTGGTAAACGGTGGACTCCTGCCTGAGGCTCCTCTCGATTTCGGTAACGCTG 300  
 301 CAAACTGGTGCCTCTTGACTATGGGTCTTGTTGGTGTGTTACGATTTCGATAGGACTTTCA 360  
 361 TTGGGTGACGGCTCTCACTAACGGCTCCAATGGGTCTGTGTTGAAACCCACTTCGGCAA 420  
 421 TGGGGTGCAGGTGAAGTCTGAAGAACGGGTATCGTCTCCAGTTACCTTGCGTGGACCAA 480  
 481 AGACTCCAACGCCAATCACCTAACAGGGTACACTATGGCTTCCGGCTCAAGTGAAGTCGGCTG 540  
 541 TTCTGCTTGTGGTCAACACCCAGGTATCACCACTGTTATCGAGCCAATCATGACTC 600  
 601 GTGACCCACACTGAAAAGATGCTTCAAGGTTTGGTGTAAAGCTCACCGGTCAAGTGATTG 660  
 661 CTGACGGGTGGTACCATCCGTCTGAAGGTGTTGCTGAAAGTCACCGGTCAAGTGATTG 720  
 721 ATGTTCCAGGGTGATCCATCCTCTACTGCTTCCATTGGTTGCTGCCCTTGCTTGTCCAG 780  
 781 GTTCCGACGTCACCATCCTTAACGTTTGTGAAACCCACCCGTACTGGTCTCATCTGAA 840

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FIG. 8

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841	CTCTGCAGGAATGGGTGCCGACATCGAAGTGATCAACCCACGTCTTGTGGAGAAG	900
901	ACGTGGCTGACTTGGGTGTTCGTCTTCTACTTGAAAGGGTGTAACTGTCAGAAAGACC	960
961	GTGCTCCTCTATGATGCCAGGATATCCAATTCTCGCTGTCAGCTGCATTGCTGAAG	1020
1021	GTGCTACCGGTTATGAAACGGTTGAAAGAACCTCCGTGTAAGGAAGCGACCGTCTTCTG	1080
1081	CTGCGCAAACGGTCTCAAGCTCAACGGTGGTGAATTGGATGAAGGGTAGACTTCTCTCG	1140
1141	TGGTGGTGGTGGTCTGACGGTAAGGTCTCGTAACGCTTCTGGAGCACGCTGTCGCTA	1200
1201	CCCACCTCGATCACCGTATCGTATGAGCTTCCTCGTATGGGTCTCGTTCTGAAACCC	1260
1261	CTGTTACTGTTGATGATGCTACTATGATCGCTACTAGCTTCCAGAGTTCATGGATTGTA	1320
1321	TGGCTGGTCTGGAGCTAAGATCGAACTCTCCGACACTAAGGCTGCTGATGAGCTC	1377

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FIG. 8(cont.)

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B

g

I

1 AGATCTATCGATAAGCTTGTAAATTGGAGGAAGATCAAATTTCATACTCCCATTTCTT  
 60 +-----+-----+-----+-----+-----+  
 1 TCTAGATAGCTTACATTAAACCTCCTTCTAGTTAAAAGTTAGGGTAAGAA  
 CGATTGCTTCAATTGAAGTTCTCCGATGGCGCAAGTTAGCAGAAATCTGCAATGGTGTGC  
 120 +-----+-----+-----+-----+-----+  
 61 GCTAACCGAAGTTAACTTCAAAGGGCTACCGGGTTCAATCGTCTTAGACGTTAACACACG  
 MetAlaGlnValSerArgIleCysAsnGlyValGln -

AGAACCCATCTCTTCAATTCTCGAAATCCAGTCAACGCCAATCTCCCTTATCGG  
 180 +-----+-----+-----+-----+-----+  
 121 TCTTGGGTAGAGATAAGGGTTAGAGAGCTTACGGTCAAGTGGTTAGAGGAATAGCC  
 AsnProSerLeuIleSerAsnLeuSerLysSerSerGlnArgLysSerProLeuSerVal -  
 TTTCTCTGAAAGACGCAGCAGCATCCACGGAGCTTATCCGATTTCGTCTGGGATTGA  
 240 +-----+-----+-----+-----+-----+  
 181 AAAGAGACTTCTGCGTCGTCTAGGTGCTCGAAATAGGCTAAAGCAGGCCACCCCTAACT

FIG. 9

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-SerLeuLysThrGlnGlnHisProArgAlaTyrrProfileSerSerTrpGlyLeuLys -

AGAAGAGTGGATGACGTAAATTGGCTCTGAGCTTCGTCCTTAAGGTCAATGTCCTCTG  
241 TCTTCCTCACTGCAATTAAACCGAGACTCGAAGCAGGAATTCCAGTAACAGAAC  
300

-ValSerGlyMetThrLeuIleGlySerGluLeuArgProLeuLysValMetSerSerVal -

SerThrAlaCysMet

FIG. 9 (cont.)

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B      q  
 1    AGATCTATCGATAAGCCTTGATGTAATTGGAGGAAGATCAAATACTTCAATCCCATTCTT  
 2    TCTAGATAGCTATTGAACTACATAACCTCCTCTAGTTAAAAGTTAGGGTAAGAA      60

61    CGATTGCTTCATTGAAAGTTCTCGATGGCGCAAGTTAGCGAAATCTGCAATGGTGTGC  
 120    GCTAACGAAAGTTAACTTCAAGAGGCTACCGCGTCAATCGCTTCAATGCGTTACACACG

MetAlaGlnValSerArgIleCysAsnGlyValGln -

121    AGAACCCATCTCTTATCTCCAATCTCTCGAAATCCAGTCAACGCAAATCTCCCTTATCGG  
 180    TCTGGGTAGAGAAATAGAGGTTAGAGGCTTACGGTCAGTTGCCTTAGAGGGAAATAGCC

AsnProSerLeuIleSerAsnLeuSerLysSerSerGlnArgLysSerProLeuSerVal -

181    TTTCTCTGAAGACGCCAGCACGATCCACGAGCTTATCCGATTCTCGTCTGCTGGGGATTGA  
 240    AAAGAGACTTCTGCGTCGTCTAGGTGCTCGAATAGGCTAAAGCAGCAGCACCCTAACT

FIG. 10

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SerLeuLysThrGlnGlnHisProArgAlaTyrProIleSerSerTrpGlyLeuLys -

AGAAGAGTGGATGACGTTAATTGGCCTCTGAGCTTCGTCCCTTAAGGTCAATGCTCTCTG  
300  
-----+-----+-----+-----+-----+-----+-----+  
241 TCTTCTCACCCCTACTGCAATTAAACCGAGACTCGAACGGAGAAATTCCAGTACAGAACGAC

LysSerGlyMetthrLeuIleGlySerGluLeuArgProLeuLysValMetSerSerVal -

TTTCCACGGGGAAAGCCGTCGGAGATTGACTTCACCCATTAGAGAAATCTCCGGTC  
360  
-----+-----+-----+-----+-----+-----+-----+  
301 AAAGGTGCCCTCTTCGAGCCTAACATGAAGTTGGTAATCTCTTAGGGCCAG

SerThrAlaGluLysAlaSerGluIleValLeuGlnProIleArgGluIleSerGlyLeu -

E

C

O

R

1

TTATAAGTTGCCCTGGCTCCAAGTCTCATCAAATAGAATTCTAAG  
361 -----+-----+-----+-----+-----+-----+  
ATAAATCAACGGACCGAGGTTCAAGAGATAGTTTATCTTAAG

IleLysLeuProGlySerLysSerLeuSerAsnArgIle

FIG. 10(cont.)

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B      9  
        1  
        I  
 1      I      AGATCTTCAAGAATGGCACAAATTACAAACATGGCTCAAGGGATACAAACCCTTAACCTCC  
        +-----+-----+-----+-----+-----+-----+-----+-----+-----+  
        60      TCTAGAAAGTTCTTACCGGTAAATTGTTGACCGAGTCCTATGTTGGAAATTAGG  
        MetAlaGlnIleAsnAsnMetAlaGlnGlyIleGlnThrLeuAsnPro -

CAATTCCAATTTCATAAACCCCAAGTTCTTAATTCTCAAGTTTCTGTGTTGGATC  
        +-----+-----+-----+-----+-----+-----+-----+-----+  
        120      GTTAAGGGTTAAAGGTATTGGGGTCAAGGATTAGAAGTCAAAAGAACAAAACCTAG  
        AsnSerAsnPheHisLysProGlnValProLysSerSerPheLeuValPheGlySer -

TAAAAAAACTGAAAAATTCAAGCAAATTCTATGTTGGTTTGAAAAGATTCAATTTTTAT  
        +-----+-----+-----+-----+-----+-----+-----+-----+  
        180      ATTTTTTGACTTTAAAGTGTAAAGATAACCAAAACTTTTCTAAAGTTAAAATA  
        LysLysLeuLysAsnSerAlaAsnSerMetLeuValLeuLysLysAspSerIlePheMet -

S      P  
        h  
        I  
 181      GCAAAAGTTTGTCTTTAGGATTTCAGCATCACTGGCTAACAGCCTGCATGC  
        +-----+-----+-----+-----+-----+-----+-----+  
        233      CGTTTCAAAACAGGAATCTAAAGTGTAGTACCCGATGTGGACGTACG  
        GlnLyspHeCysSerPheArgIleSerAlaSerValAlaThrAlaCysMet

**FIG. 11**

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FIG. 12

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SerMetLeuValLeuLysLysAspSerIlePheMetGlnLysPheCysSerPheArgIle -  
TCAGGCATCAGTGGCTACAGCACAGAACGCTCTGAGATACTGTGCAACCCATTAAAGAG  
300  
-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+  
AGTCGTAGTCACCGCATGTCGTGTCAGACTCTATACAACGTTGGTAAATTTCCTC  
241  
-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+  
SerAlaSerValAlaGlnLysProSerGluIleValLeuGlnProIleLysGlu -  
E C O R 1  
-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+  
ATTTCAGGCACTGTTAATGGCCTGGCTCTAAATCATTATCTAAATAGAAATT  
301  
-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+  
TAAGTCCGTACAATTAAACGGACCGAGATTAGATAATAGATTATCTTAAG  
IleSerGlyThrVallysLeuProGlySerLysSerAsnArgIle

FIG. 12 (cont.)

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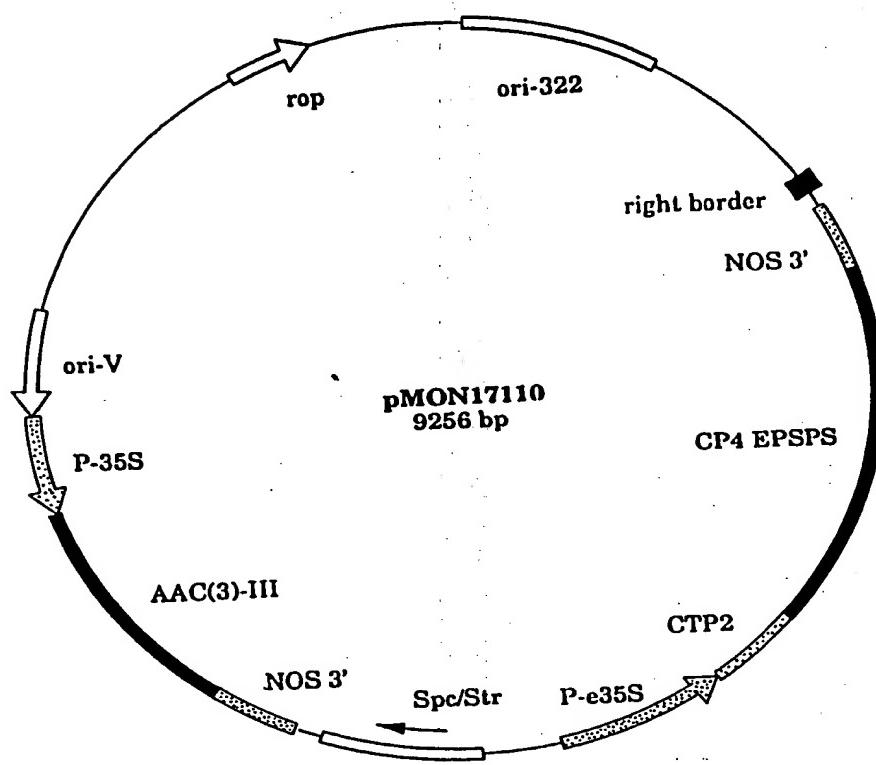


FIG. 13

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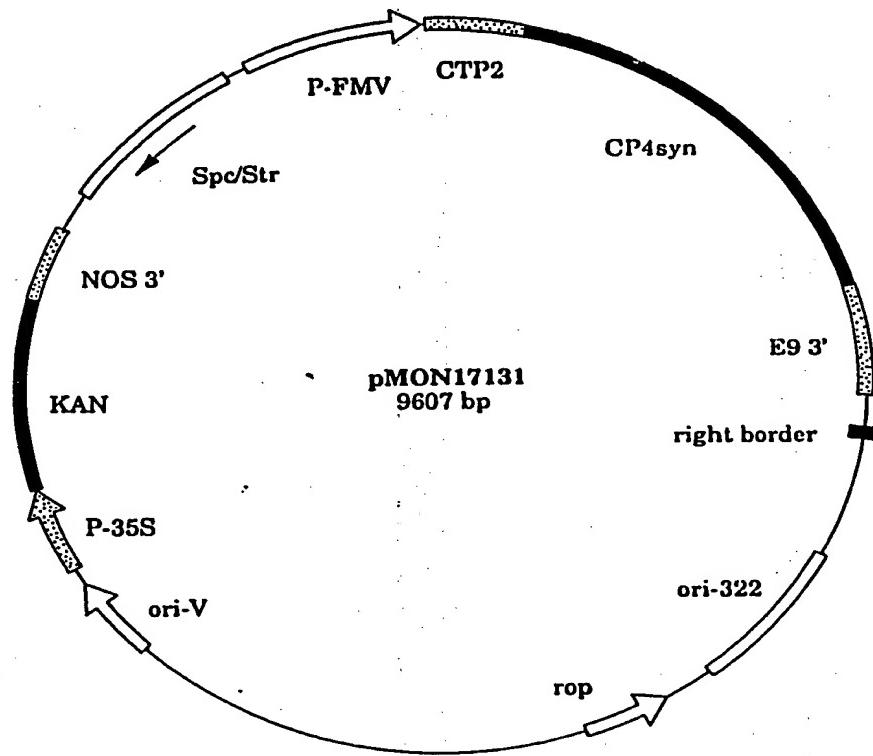


FIG. 14

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SUBSTITUTE SHEET

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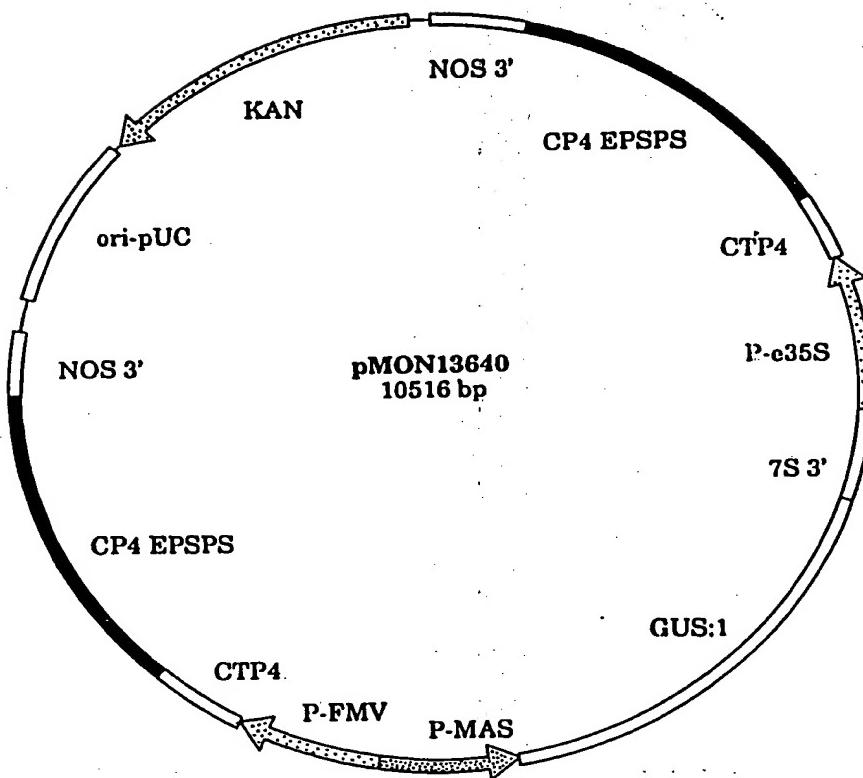


FIG. 15

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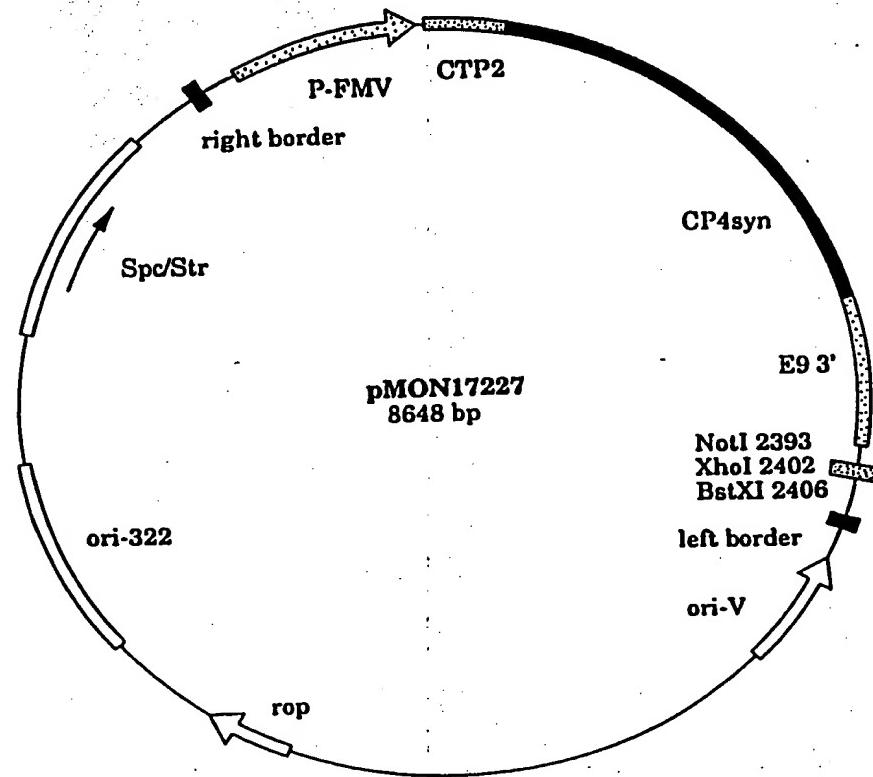


FIG. 16

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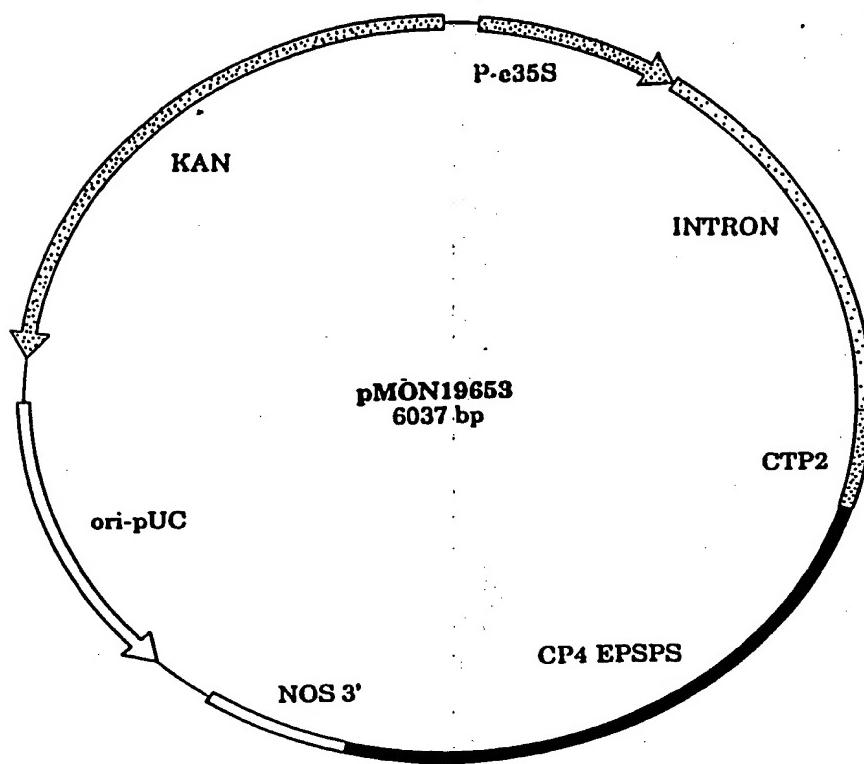


FIG. 17

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## INTERNATIONAL SEARCH REPORT

International Application No.

PCT/US 91/06148

I. CLASSIFICATION & SUBJECT MATTER (If several classification symbols apply, indicate all)<sup>a</sup>

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 C12N15/54; C12N15/82; C12N5/10; A01H5/00

## II. FIELDS SEARCHED

Minimum Documentation Searched<sup>b</sup>

Classification System	Classification Symbols
Int.Cl. 5	C12N ; A01H

Documentation Searched other than Minimum Documentation  
to the Extent that such Documents are included in the Fields Searched<sup>b</sup>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>c</sup>

Category <sup>d</sup>	Citation of Document, <sup>e</sup> with indication, where appropriate, of the relevant passages <sup>f</sup>	Relevant to Claim No. <sup>g</sup>
A	EP,A,0 218 571 (MONSANTO) 15 April 1987 see example 8	1-30
A	EP,A,0 293 358 (MONSANTO) 30 November 1988 see the whole document	1-30
O,A	PLANT PHYSIOLOGY. vol. 89, no. 4, April 1989, ROCKVILLE, MD, USA. page 47; EICHHOLTZ, D., ET AL.: 'Glyphosate tolerant variants of petunia EPSP synthase' see the abstract no. 277	1-30 -/-

<sup>a</sup> Special categories of cited documents :<sup>10</sup><sup>b</sup> "A" document defining the general state of the art which is not considered to be of particular relevance<sup>c</sup> "E" earlier document but published on or after the international filing date<sup>d</sup> "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)<sup>e</sup> "O" document referring to an oral disclosure, use, exhibition or other means<sup>f</sup> "P" document published prior to the international filing date but later than the priority date claimed<sup>g</sup> "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention<sup>h</sup> "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step<sup>i</sup> "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art<sup>j</sup> "A" document member of the same patent family

## IV. CERTIFICATION

Date of the Actual Completion of the International Search  4 11 DECEMBER 1991	Date of Mailing of this International Search Report  17.01.92
International Searching Authority  EUROPEAN PATENT OFFICE	Signature of Authorized Officer  MADDOX A.D. 

International Application No.

PCT/US 91/06148

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A	CHEMICAL ABSTRACTS, vol. 112, 1990, Columbus, Ohio, US; abstract no. 92785, page 196 ; see abstract & DISSERTATION 1988, AVAIL. UNIV. MICROFILMS INT., ORDER no. DA 8917814. From Diss. abstr. int. B 1989,50(5), 1770-1771 FITZGIBBON, JOSEPH E.: 'Pseudomonas strain PG2982: uptake of glyphosate and cloning of a gene which confers increased resistance to glyphosate' ---	1-30
A	US,A,4 769 061 (COMAI) 6 September 1988 see column 6, line 61 - column 7, line 11 ---	26-30
A	SAAS BULLETIN vol. 1, 1988, pages 37 - 40; LARSON-KELLY, N., ET AL.: 'Chloroplast delivery of a bacterial EPSP synthase in transgenic plants and tolerance to glyphosate' see page 38, line 37 - line 42 ---	26-30
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ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.US 9106148  
SA 51938

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.  
 The members are as contained in the European Patent Office EPO file on  
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